1.0 Introduction

My son's first year in scouting we set about building a Pinewood Derby car with no previous experince. We found a dizzying amount of information on the internet, some of it contradictory and some of it designed for races with different rules then the Cub Scouts practice. This guide explains how to build a fast Cub Scout Pinewood derby car based on our experiences building cars for the 2002, 2003 and 2004 Pinewood derby races for Pack 50, Georgetown, Massachusetts. During this time my son's cars finished first twice and thrid once at the pack races and finished sixth, third and first at the district races. This guide will begin by discussing some selected car rules and the "standard" track to set the stage for the later sections, we will then cover each of the key elements required to build a fast car with detailed step-by-step instructions.

2.0 Safety and participation

Before discussing anything else a word about safety. Some of the techniques covered in this guide require the use of power tools. It is up to you as the adult partner to determine what is and isn't safe for the scout to do based on the scouts age, experience and maturity. When in doubt ere on the side of caution.

The objective of the Pinewood derby is for the adult partner and scout to build the car together. As much as you can safely allow the scout to do the work you should. Clearly a tiger cub should never use power tools so they may be able to only handle sanding and painting the car but as the scout gets older they should do more and more of the work themselves. Many older scouts make their own cars without adult intervention although adult supervision would certainly be appropriate.

And always remember that Pinewood derby is all about fun!

3.0 The rules

The following are a few selected rules around car dimension, this is not a complete set of rules, please be sure and get a set of the official rules for your pack and read them closely. The pinewood derby cars come with a set of rules included, your pack may or may not use those rules, the pack's rules take precedent:

- Length cannot exceed 7 inches.
- Width cannot exceed 2-3/4 inches.
- Width between wheels must be at least 1-3/4 inches (the lane guide is 1-5/8" wide so 1-3/4 provides 1/8" of clearance, see figure 1).
- Bottom clearance between the car and the track must be at least 3/8 inch (the lane guide is ¼" thick so 3/8" provides 1/8" of clearance, see figure 1).
- Weight cannot exceed 5 ounces.

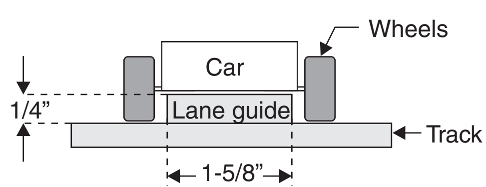

Figure 1. Car and lane guides.

4.0 The track

The "standard" track is 32' long with a 4' drop and is made of wood, see figure 2. The car travels from the starting gate approximately 28' to the finish line. The car starts on an incline of approximately 30^{o} and is held back by a ¼” wooden dowel. When the race starts the dowel pivots down into the track, the car accelerates down the incline for approximately 10' and then coasts along a flat section of track for approximately 18' to the finish line. This is the track described in the Boy Scout’s leader book, but tracks vary widely in length, configuration and materials of construction, for example Pack 50 has an additional 8 foot section at the end of their track for a 40 foot overall length.

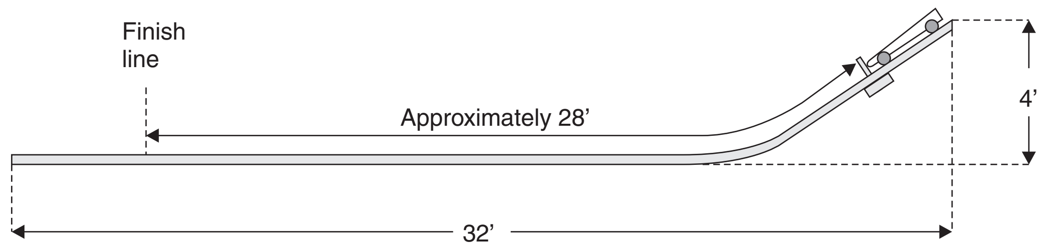

Figure 2. The “standard” track.

5.0 Physics

Ok, I don’t want to scare anyone, but some basics make it a lot easier to understand what matters in car design and why.

Before the race has started your car will be sitting against a pin on an approximately 30^o incline. At this point the car has potential energy due to gravity trying to pull the car down the incline. This is the greatest amount of energy the car will ever have! The potential energy depends on the mass (weight) of the car and the distance the center of mass will fall (more on this later). When the pin drops out of the way, the car begins to accelerate down the track and the potential energy is converted to kinetic energy (speed) and heat due to friction. Energy is always conserved so the total energy in the system will always be the same. What this means is that at the top of the ramp the car has only potential energy and at the bottom of the ramp all of the potential energy has been converted to kinetic energy and heat. The more friction in the car the more energy that becomes heat and is lost from the car into the surrounding air and the track. More importantly any potential energy that become heats is no longer available to become kinetic energy (speed). Once your car has reached the bottom of the ramp the car has as much kinetic energy (speed) as it will ever have and the car coasts from the bottom of the ramp to the finish line slowing down continuously due to heat lost from friction.

6.0 Factors that make a car fast

The are only three things that matter to making a car fast:

1. Mass and center of mass - the car should weight the maximum amount allowed and the center of mass should be positioned so it falls as far as possible.
2. The wheels and axles need to be designed to minimize friction - the wheels need to be perfectly round and smooth, the axles need to be smooth, the wheels need to be perfectly aligned and the wheels and axles need to be well lubricated.
3. Aerodynamics - the car should push the minimum amount of air possible and be as smooth as possible

In the balance of this guide we will describe step by step how to achieve all three of these goals at once. Many guides we have seen (and we have read most of them) talk about a lot of ideas and tricks that just don’t matter. If you do all three of these things right you win.

7.0 Axles

The axles provided with the BSA kit are steel nails. As a first step inspect the nails and make sure they are not visibly bent. The axles as provided have ridges on the axle shaft and on the inside of the axle head, see figure 3. The wheel will rotate on the axle shaft and rub against the inside of the axle head, these areas need to be as smooth as possible.

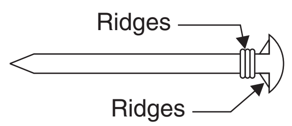

Figure 3. Axle before smoothing

7.1. Smoothing the axles:

- Mount the pointed end of the axle in the chuck of a drill press. If all you have is a drill, clamp the drill in place for these steps.
- Start the drill spinning.
- Use a small jewelers file to file the ridges off of the axle shaft and the inside of the axle head. Check the axle frequently and only file enough to smooth out the ridges.
- File the inside of the head at a slight angle so the wheel will only contact the head right at the shaft of the axle, see figure 4.

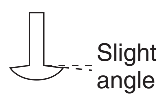

Figure 4. Axle head detail.

I have a small block of wood I have cut at a 5 degree angle I use as a guide for this. By making the wheel rub against the axle head at only the center you reduce the friction and lessen the effect of friction on the wheel. It is easier to stop a spinning wheel by grabbing the wheel at the outer edge than at the center so try to keep all friction at the wheel center.

- Find or make a long thin block of wood, cut square and small enough to fit between the head of the axle and the chuck of the drill. Cut one edge of the block at a 5 degree angle. For the next three sanding steps sand paper is wrapped around the wood to provide flats surfaces for sanding, see figure 5.

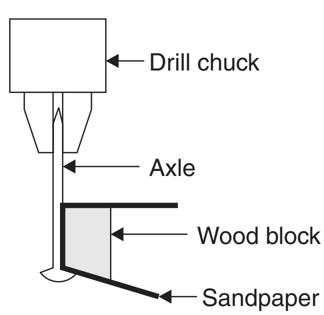

Figure 5. Sanding the axle.

- Start sanding with 320 grit wet and dry sandpaper. The paper should be wet with WD40. Wrap the paper around the wood block and hold the block against the axle so the shaft of the axle and the inside of the axle head are both sanded. Move the block up and down the shaft to create a smoothed area longer than the wheel width. Sand only long enough to replace the scratches from the file with the smaller scratches from the sand paper. After sanding hold a piece of paper towel against the spinning shaft to wipe off the oil and particles created by sanding.

- Follow the 320 grit wet and dry sand paper with 600 grit wet and dry sand paper following the same procedure.
- Follow the 600 grit wet and dry sandpaper with 1200 grit wet and dry sandpaper following the same procedure.
- Following sanding with 1200 grit paper the axle should be quite shiny. Dip a soft cloth in Mother's Aluminum polish and apply a small amount to the spinning axle. Allow the polish to sit on the axle for 30 seconds and then buff off with a piece of clean terry cloth.
- Stop the drill and remove the axle. The axle should be mirror smooth even when viewed under a magnifying glass.

Repeat this procedure to make 4 axles. The time to make 4 good axles this way is 1 to 2 hours. Many older scouts can probably do this work themselves.

8.0 Wheels

The wheels as provided from the Boy Scout’s have a large mold mark in the tread of the wheels, they also may not be perfectly round. There are several molds used to produce these wheels and some are better than others.

8.1. Smoothing the wheels

- Mount the wheel in a collet. Collets are available from the BSA or many hobby shops.
- Mount the collet in a drill press and start the drill spinning. Use a low speed to prevent melting the wheel during sanding.
- Hold a piece of 60 grit sandpaper against the spinning wheel with a flat block of wood. Be careful to keep the wood parallel to the wheel surface, see figure 6, the outside edge of the wheel has small ridges that race rules may require are intact. Sand the wheel only long enough to remove the dimple left in the wheel from molding. You need to apply only light pressure here, too much pressure can overheat the wheel softening the plastic and causing it to wrip off in chunks.

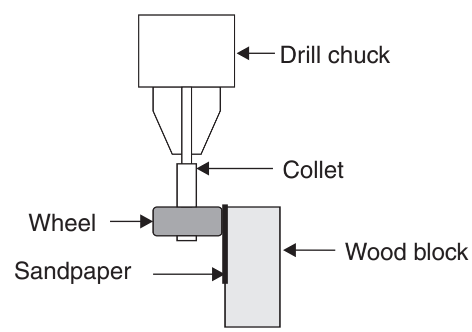

Figure 6. Sanding the wheel.

- Follow the 60 grit sandpaper with 150 grit sandpaper using the same procedure. Sand only long enough to replace the deep groves from the 60 grit paper with the smaller groves from the 150 grit paper. Hold a piece of paper towel briefly against the spinning wheel to clean off any plastic bits from sanding.

- Follow the 150 grit sandpaper with 220 grit sandpaper using the same procedure. Sand only long enough to replace the groves from the 150 grit paper with the smaller groves from the 220 grit paper. Lightly sand the inside edge of the wheel. Hold a piece of paper towel briefly against the spinning wheel to clean off any plastic bits from sanding.
- Follow the 220 grit sandpaper with 320 grit wet and dry sandpaper using the same procedure. Wet the 320 grit sandpaper with water before use. Sand only long enough to replace the groves from the 220 grit paper with the smaller groves from the 320 grit paper. Lightly sand the inside edge of the wheel. Hold a piece of paper towel briefly against the spinning wheel to clean off any plastic bits from sanding.
- Follow the 320 grit sandpaper with 600 grit wet and dry sandpaper using the same procedure. Wet the 600 grit sandpaper with water before use. Sand only long enough to replace the groves from the 320 grit paper with the smaller groves from the 600 grit paper. Lightly sand the inside edge of the wheel. Hold a piece of paper towel briefly against the spinning wheel to clean off any plastic bits from sanding.
- Follow the 600 grit sandpaper with 1200 grit wet and dry sandpaper using the same procedure. Wet the 1200 grit sandpaper with water before use. Sand only long enough to replace the groves from the 600 grit paper with the smaller groves from the 1200 grit paper. Lightly sand the inside edge of the wheel. Hold a piece of paper towel briefly against the spinning wheel to clean off any plastic bits from sanding.
- Stop the drill and remove the wheel from the collet. The wheel surface should be shiny and smooth.

Repeat the procedure to make 4 wheels.

9.0 Lubricating the wheels and axles

It is essential to lubricate any surfaces that will rub against each other or anything else. This procedure is for the dry graphite such as Hob-E Lube or Pine Pro. Do not use the BSA White Teflon, we have tested it versus Graphite and it is not nearly as fast. Pine Pro is faster than Hob-E Lube but harder to use requiring just the right amount of work-in before a race and wearing off faster than Hob_E Lube.

- Sprinkle graphite onto an axle. Try to coat all of the surfaces the wheel will rub against.
- Sprinkle graphite into the opening in the wheel that the axle will go through and onto the outer and inner hub of the wheel.
- Insert the axle into the wheel and place the pointed end of the axle into the drill. Start the drill.
- Hold the wheel so the axle is spinning inside the stationary wheel.
- Continually sprinkle graphite into the gap between the wheel and axle while spinning the wheel.
- The graphite will melt into the inside of the wheel. The longer you spin-in the graphite the better.
- Once you have spun-in an axle inside a wheel keep the axle and wheel together as a matched pair.
- Before each time you race the car, sprinkle on more graphite and spin the wheels. Some people use a Dremel tool to spin the wheels on the car. Spinning the wheels before a race will make a car go faster but the effect only lasts for about 30 minutes.

10.0 Weight and weight distribution

From the discussion of the track and physics presented previously, we know that we want an ideal car to gain as much speed as possible in the initial sloped section of the track and lose as little speed as possible in the flat section of the track.

10.1. Effect of weight

Neglecting friction, any two object dropped from the same height will hit the ground at the same time. On the sloped section of the Pinewood derby track, gravity is trying to pull the cars straight down to the ground and the track is forcing the cars to travel down the slope to get there. If two cars reach the bottom of the inclined section of the track at the same time, then the heavier car will carry more momentum into the flat section of the track and be harder to stop keeping it's speed longer. On the sloped section of the track - neglecting friction, the heavier and the lighter car should both accelerate at the same rate. The heavier car may have more friction in the wheels and axles when it is rolling, but tests have shown that the greater momentum is more important and that heavier cars are faster.

10.2. Effect of center of mass

In the starting gate a Pinewood derby car is held back by a ¼" dowel blocking the nose of the car. When the race starts and the dowel drops out of the way the car will accelerate until the center of mass of the car reaches the flat section of the track. If the center of mass of the car is near the nose, the center of mass will not fall as far as if the center of mass is at the back of the car. If you take a car and balance the car from front to back on a sharp edge set cross wise under the car, the balance point is the center of mass. Figure 7 illustrates how the position of the center of mass effects the distance the center of mass falls and therefore the potential energy.

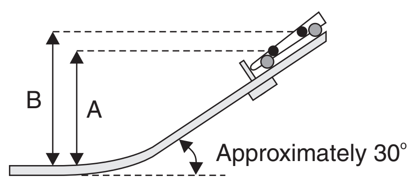

Figure 7. Effect of center of mass.

In figure 7, when the center of mass is near the nose of the car the car vertically "falls" distance A and when the center of mass is near the rear of the car the car "falls" distance B. Since distance B is greater than distance A, the car with the center of mass in the rear will "fall" farther and therefore accelerate more all other things being equal.

The preceding analysis suggests that the further back in the car the center of mass is the faster the car. There are however other concerns with weight distribution. If the weight is too far back relative to the rear wheels the front end of the car may bounce or even "pop a wheely" making the car unstable. Generally speaking the center of mass of the car should be 1" - 1-1/2" in front of the rear axle. The official block of wood has the axle slots closer to one end then the other. We use the end with the axles closest to end of the block as the back of the car to allow us to move the center of mass as far back as possible. We center the weight from side to side to help the car roll straight.

10.3. Setting the weight and weight distribution

Once the car body is cut to shape, the car body, wheels and axles will weight less than 5 ounces. Cars with low profiles for good aerodynamics typically are well under weight. Adder weights are available from a number of sources with flat weights and cylinder weights being quite common. We use cylinder weights. We drill 3 - 3/8" holes into the back of the car extending in for approximately 3". We then weigh the car and wheels and slide the required amount of weight into the holes adding weight symmetrically from side to side. The weight will be quite snug and you can slide it in different amounts until the weigh distribution is correct. The weight distribution may be checked by balancing the car on the edge of a ruler and finding the point between the front and the rear of the car where it just balances. Glue the weights in place once the balance is found. To make the weights slide more easily file the ridges off of the weights that are left by the casting process.

11.0 Aerodynamics and car design

A basic car design that produces minimum drag and proper weight distribution is illustrated in figure 7. Some people say that aerodynamics don't matter. I would agree that the weight, weight distribution, axles and wheel matter more, but when you see races end in a tie with ten thousands of a second timing you realize that everything matters!

The steps to building this car are:

- Drill the three holes 3/8" holes - 3" deep for the weights so that the weights are just above the axle slots leaving approximately 1/16" of clearance.
- Cut the car to thickness on a table or other saw so that 1/8" is left above the tops of the holes for the weight.
- Cut the angle for the nose.
- Using a dremel tool mill out the top slots between the weights.
- Shape the car to final dimensions with a palm sander and 60 grit sandpaper.
- Sand the car and paint.

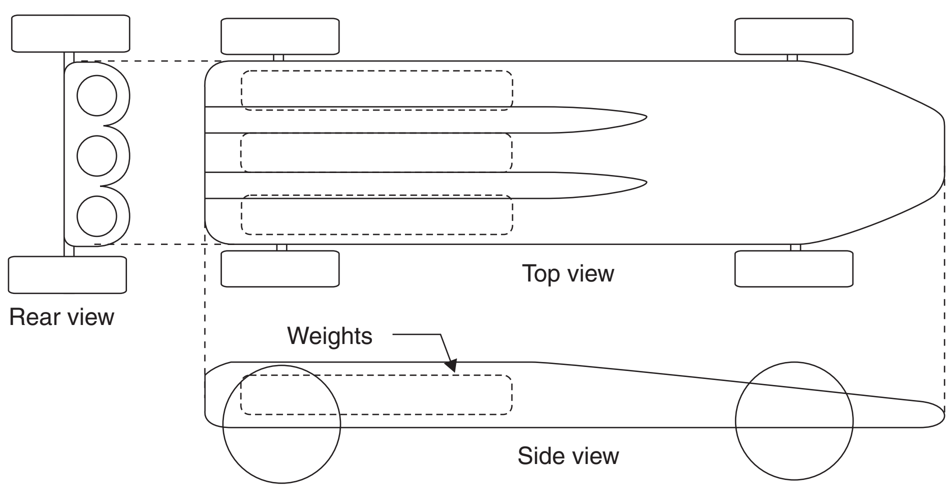

Figure 8. Car design.

The car in figure 7 features all rounded edges and slots cut around the weights to minimize the cross sectional area. On the finished car there is only 1/8" of wood surrounding the weights! The only way to create a car with less cross section would be to use flat weight recessed into the bottom. This car also locates the wheels near the rear to allow the weight to be located near the back for optimum weight distribution (see the next section). The car requires 3 full cylinder weights with a small added piece to reach racing weight.

12.0 Mounting and aligning the wheels

- Slide the pointed ends of the axle into the pre-cut slots in the car body. Using a BSA alignment tool align the wheel.
- Make sure all of the wheels are touching and the car will roll straight. Glue the axle in place with clear hot glue. The hot glue will allow you to remove the wheels and axles to clean and lubricate them as

needed. Some people set the wheels so only 3 are touching down on the idea that this will produce less friction. Our experience is that the car bounces around more and is slower.

- Put the car on a flat - smooth surface and try rolling it forward and back, make sure all four wheels turn, the car tracks straight and that the wheels don't move in towards the body or out away from the body as the car moves.
- Store the car on its back or on a small stand to prevent the minimize the chance of the wheels being knocked out of alignment. Note this doen't work for the car in figure 8, it is so thin it will roll on it's back, we stire our cars up on blocks of wood with teh wheels up in the air.

