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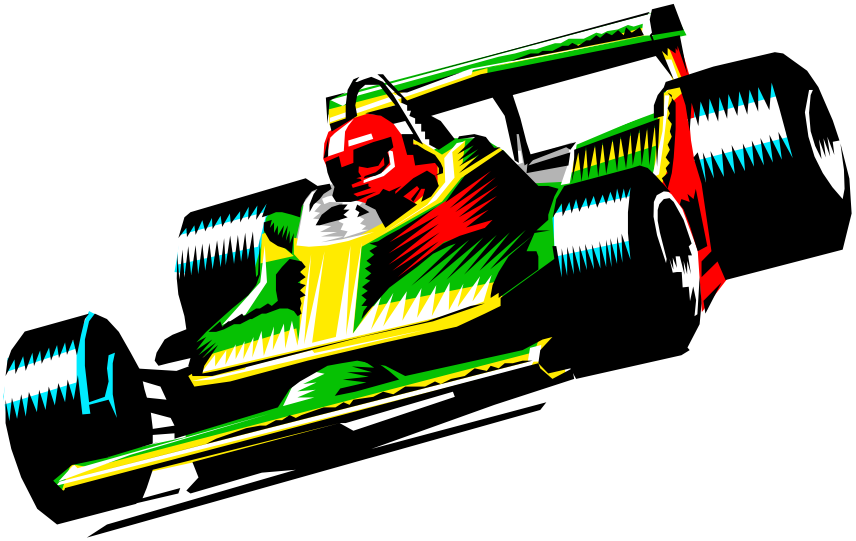

Pinewood Derby Car Construction Guidelines

Sixth Edition

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Maximum Velocity!

Pinewood Derby Car Construction Guidelines

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by

Randy Davis

Maximum Velocity!

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Maximum Velocity!

Pinewood Derby Car Construction Guidelines

Introduction

Welcome to the world of Pinewood Derby racing! This booklet provides you with the information needed to build a Pinewood Derby car which reaches its *Maximum Velocity*!

A competitive car can be built with the car kit and basic tools and supplies. However, for best results you will need the following additional supplies, which are available at most Hobby shops:

- Wheel Mandrel
- Graphite/Molybdenum Lubricant
- Polishing compound (See "Axle Preparation" - Page 14)
- 600 Grit Wet/Dry Sandpaper
- Exacto knife and blades
- Lead weight

To achieve *Maximum Velocity!*, you must fully understand the car construction process, and allocate adequate time to the building process. Please read the entire booklet *before* beginning construction, and pay special note to the time schedule on page 21.

> ***Important!***
>
> Be sure to read and understand the local rules for your race. Some of the techniques described in this booklet *may not be allowed* in your race. ***If the rules are not clear, then ask the race leader for clarification.***

To the Adult

The purpose of the Pinewood Derby is to provide a project for an adult and child to enjoy together. Thus, the child and the adult should make the car together as a project. The intent is not for the adult to show the child the garage door then walk away; nor is it the intent that the child play video games while the adult builds the car[1]. In order for the car to be a joint project, the adult should allow the child *to do as much work on the car as he/she can physically and safely accomplish*. The amount of work that the child can do will clearly vary from individual to individual, however, here are some general guidelines:

Preschool - Preschoolers will not likely have the attention span nor the dexterity to be very involved in the construction process. Let them do as much as they can, but mainly use the opportunity to show them that you care enough to build them a car. Preschoolers can participate by helping select the car design, gluing parts on the car, and 'personalizing' the car with markers and/or stickers.

Kindergarten to Grade 2 - These children will probably be very interested in the car project, if you let them help as much as possible. Use the opportunity to spend some time with your child and show them the purpose for and proper use of tools. Allow the child to select the car design, and assist in the construction process by handing tools to the adult. The child can also do some of the sanding, and apply the car numbers and the logo stickers. Consider allowing the child to paint the car with a brush and perform other personalization.

Grade 3 and 4 - Children of this age are old enough to learn how to properly use hand tools. Use the project as an opportunity to teach the child basic skills. They should be able to perform all of the work on the car (with supervision of course) *except those steps that involve sharp cutting edges.*

Grade 5 and above - These young people are old enough to build the car themselves with the exception of using major power tools. However, the car project gives you an excellent opportunity to coach the individual in craftsmanship and delayed gratification. Many young people want to skip as many of the 'boring' steps as possible, and just 'get those wheels on the car.' They are then disappointed when the car performs poorly on the track. Instead, encourage the young person to work through the steps, helping him/her to understand that the more effort and hard work they put into the car, the better the result will be on the track.

[1]Thanks to Randy Worcester of Madison, Mississippi for this thought.

Reaching Maximum Velocity!

There are four key principles[2] that must be followed in order to reach *Maximum Velocity!* The features are:

1. **Wheel Alignment** - The wheels must be perfectly aligned, such that the car rolls in a straight line (see "Wheel Alignment" - Page 16). If the car does not roll straight, nothing else matters!
2. **Axle/Wheel Preparation** - The rolling surface and inside edge of the wheels must be smooth and free of any defects, and the axles must be smooth (see "Wheel Preparation" - Page 10 and "Axle Preparation" - Page 13).
3. **Lubrication** - The wheels/axles must be lubricated with an appropriate material (see "Lubrication" - Page 15).
4. **Weight** - The car must be properly weighted (see "Adding Weight to the Car" - Page 7). The weight must also be positioned properly (see "Positioning Weight" - Page 9). An underweight or improperly weighted car will not reach its *Maximum Velocity*!

If the car has these features, it will be fast. However, there are many additional ways in which ingenious builders have further improved the speed of their cars. Many of these methods are described in this booklet. The car builder may try any method as long as the car adheres to the specifications and the local rules. If you are interested in learning other speed tips, many are included on page 17, and several Pinewood Derby-oriented pages exist on the Internet (see "Bibliography" - Page 26).

An Important Speed Tip for Car Builders!

When you have completed the construction process and are waiting for the weigh-in, store your car in a safe place, away from dust and/or contaminants (a shoe box with some padding works well). ***Do not play with the car until after the race***. By rolling it around on the floor, the car will pick up dust and dirt on the wheels and axles, and the axles will likely become misaligned.

[2]Some of the techniques described in this booklet (or found elsewhere) may seem to provide very minor, to insignificant improvements in performance. But recognize that at the finish line, the winning car usually has only a fraction of an inch advantage over the next several cars. Therefore, any improvement in a car's performance, even a seemingly insignificant improvement, could mean the difference between winning or not winning a trophy.

Car Specifications

The following specifications should match the official rules included with the car kit. However, if there is a conflict between the information in this booklet and the official rules, the official rules should be followed.

All Pinewood Derby cars must be built within the following dimensions (see Figure 1):

- Overall length not greater than 7"
- Overall width (including any accessories) not greater than 2-3/4" (prevents interference with neighboring cars)
- Overall height not greater than 3" (prevents interference with finish line detector). This measurment may vary from race to race.
- Bottom clearance no less than 3/8" (prevents dragging on lane guide)
- Inside wheel width no less than 1-3/4" (prevents dragging on lane guide)

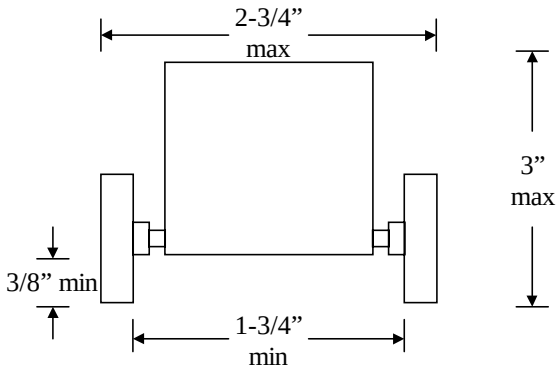


FIGURE 1
Car Dimensions

In addition, the following specifications must be followed:

- Only the wheels and axles provided in the car kit may be used.
- No washers or bushings may be placed on the axles (i.e., the wheels must be the only objects on the axles, and nothing can be placed between the wheels and the body).
- No starting devices are allowed (gravity alone must power the car).
- All body parts/weight must be securely fastened.

Steps to Building a Pinewood Derby Car

The following steps provide an outline for building a Pinewood Derby car. Although there can be some overlap, it is generally best to build the car in the given order. Please note the references to other chapters and refer to those chapters as needed. A time schedule is shown on page 21.

1. **Create a Design for the Car** - The variety of possible shapes is unlimited, however, the final car must adhere to the required dimensions. Avoid designs which have a sharply pointed front end. These cars don't stage well at the starting gate, and may not register properly on the finish line sensor. Also, make sure that the front and back of the car are obvious. You don't want the car to be placed backwards on the track!

   If you do not have a design in mind, the companion booklets *Car Plans*, *Car Plans II*, *Advanced Car Plans*, and *Unique Car Plans* each provide complete plans for three different car styles.

   Note: See "Aerodynamics" - Page 7. Also, as part of the design process, determine how weight will be added to the car (see "Adding Weight to the Car" - Page 7 and "Positioning Weight" - Page 9)

2. **Shape the Wood Block** - Create cavities to hold weight (adult supervision is suggested for any step that uses power tools or sharp cutting edges). Then saw, file, and sand the block to achieve the desired look.

   *Note: **If allowed by your local rules**, you may move the axle location by cutting new slots, or by drilling axle holes. If you drill axle holes, make sure the block is square (They typically are not square!). If you use the existing slots, and one of the slots is closer to the end of the block, use that slot for the rear axle.*

3. **Sand the Car** - Progress from coarser to finer sandpaper to achieve the desired finish. *Be sure to wear a particle mask when sanding!*

4. **Apply a Primer** - Follow the manufacturer's recommendations for number of coats and drying time and use 600 grit sandpaper to lightly sand the car between coats.

5. **Apply Paint** - Use a brush, air brush, or spray can to apply several finish coats of paint. Lightly sand the car with 600 grit sandpaper between coats. After the last coat, you may want to apply a clear finish.

   Note: Avoid enamel paint (which takes a long time to dry). Instead use an acrylic spray paint such as "Krylon", or acrylic brush-on paints.

6. **Add Weight** - Use a postal scale or kitchen scale to set the weight just over 5 ounces. The weight will be reduced to 5 ounces at the weigh-in.

   Note: Make sure to weigh the wheels and axles with the car.

7. **Accessorize** - Add any desired decorations/accessories to the car.

   Note: Stay within the overall limits on height, length, and width.

8. **Apply Numbers** - Use the stickers included in the kit or apply the numbers using paint or a marker. However you apply the numbers, they must be ***legible, permanent, and easily located***.

9. **Prepare the wheels and axles** - Page 10 and 13

10. **Apply Lubrication** - Page 15

11. **Attach Wheels/Axles** - To keep the wheels aligned and free of paint, saw dust, and other debris, attach your wheels and axles after everything else is completed. Press the axles into the axle slots with your hand, or use pliers to twist them into the slots.

12. **Align Wheels** - Page 16

13. **Glue Axles to Body** - To keep the axles from becoming misaligned during the race, place glue in the axle slots on top of the axles (see Figure 2). Use epoxy, hot glue, white glue, or a similar product. *Keep the glue away from the wheels!* Remove excess glue, making sure that the glue does not hang down below the car, reducing the clearance to less than 3/8". Set the car on its back to dry for 24 hours.

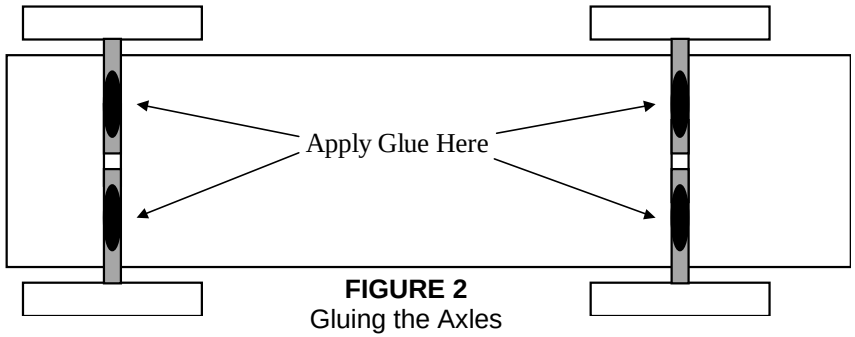


FIGURE 2
Gluing the Axles

Important!

Apply glue to the axles at least 24 hours before the weigh-in. If the glue is not dry, the wheels could become misaligned during the weigh-in and staging/storage process. Do not use a thin glue such as super glue. The glue may run down the axle causing the wheels to become glued to the axles.

Aerodynamics

Having an aerodynamic car will provide some speed advantage, but not as significant as the factors listed on page 3. To build an aerodynamic car, here are some factors to consider:

1. The front of the car should be rounded such that the block shape is eliminated. A wedge shape works well as it provides space in the rear to add weight.
2. The car should *not* have any accessories which add wind drag. Thus, air-catching accessories, such as paper or cloth flags, tails, air spoilers, etc., should be avoided.
3. Lead takes up less space than wood, therefore, remove as much wood as possible and replace it with lead.

Adding Weight to the Car

There are countless ways in which weight can be added to a car. The weighting methods can be classified as adjustable and non-adjustable. Adjustable means that weight can be easily added or removed at weigh-in time without using a drill. Non-adjustable means that you cannot easily add weight at weigh-in, and you can only remove weight by using a drill. The following are some of the more common methods.

Cargo Weight

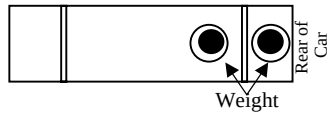
The car can be built to carry weight as the cargo. The design can use either adjustable or non-adjustable weight. For example:

- Truck/train car with cargo in the bed. The cargo can be pennies, lead fishing weight, washers, bolts, etc. The design can be made adjustable by putting a small, latchable container (film container, medicine container, etc.) in the bed, which in turn holds the weight. Make sure that the weight is firmly attached.
- Car with weighted people, weighted luggage, or even a weighted motor.
- How about a wagon, a boat, a sled, a baby carriage, ...

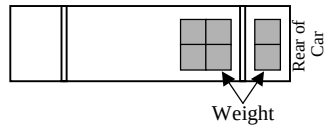
Non-Adjustable Hidden Weight

Most designs can accommodate non-adjustable weight hidden on the car. The key to non-adjustable weight is to make sure that the car weighs slightly more than 5 ounces. At weigh-in, any excess weight can be removed with a drill.

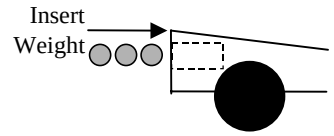
Some possibilities are:



- **Lead Underneath** - Drill a hole(s) in the bottom of the car and glue lead weight into the hole(s).



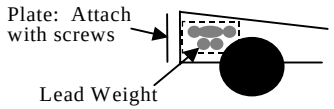
- **Segmented Weights** - Segmented lead weights (sold at many hobby stores) can also be placed under the car. To maintain the minimum ground clearance, *a pocket must be created* in the bottom of the car to hold the weight.



- **Lead in Back** - Lead fishing weights can also be inserted into holes drilled in the back of the car. Insert enough lead to bring the weight of the car to just below 5 ounces. Then place a piece of lead under the car. At the weigh-in, the underbody weight can be drilled to adjust the weight of the car.

Adjustable Hidden Weight

Most designs can also accommodate some form of adjustable hidden weight. Here are some possibilities:



- **Weight In Back of Car** - Drill out a pocket in the rear of the car large enough to accommodate enough lead fishing weight to bring the car up to 5 ounces. Cut a small piece of sheet metal or plastic to act as a cover, and screw the cover over the hole. At weigh-in, the cover can be removed, weight added or subtracted, and the cover replaced.
- **Weight Under Car** - The same method described above can be used under the car. However, the pocket will likely need to be wider but less deep, thus requiring a larger plate. The plate should be recessed to ensure that the minimum clearance is still achieved when the plate is attached.

Caution!

Lead is the preferred weighting material as it is very dense and easily shaped. Note that the weighting material sold for use with Pinewood Derby cars (PineCar brand) is not lead, and some fishing weight is not lead.

Lead is toxic, so wash your hands after handling lead; keep lead away from food, water, and food preparation areas; and collect and properly dispose of any lead pieces. Avoid melting lead, as lead fumes are toxic, and the lead can pop and/or splatter during the melting process causing eye and skin injuries.

Positioning Weight

The location of the weight on the car contributes significantly to reaching *Maximum Velocity!* The best location for the weight depends on the track style (see Figure 3). The rest of this booklet will be based on the 'Ramp and Flat' track', which seems to be the most popular variety.

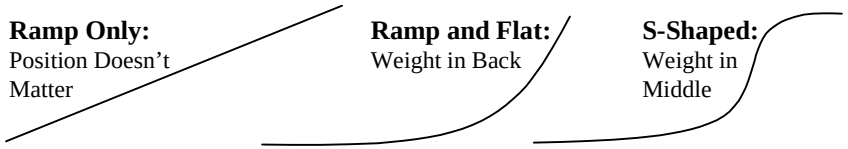


FIGURE 3
Positioning Weight

The following guidelines should be used when positioning weight on a car:

1. The best location for the center of gravity[3] is between 3/4" and 1-1/4" in front of the rear axle. If the center of gravity is closer to the rear axle, the front end of the car will be too light. If the center of gravity is closer to the front of the car, the car will not reach *Maximum Velocity!*
2. ***If allowed by the local rules***, the axles can be moved closer to the ends of the car by cutting new axle slots or by drilling axle holes. This allows the center of gravity to be moved even further backward (Also, moving the front axle forward makes wheel alignment easier).
3. The car should be maximum length. Shorter cars will have a shorter distance to drop and will not reach *Maximum Velocity!*

The lengthwise location of the center of gravity of a Pinewood Derby car can be easily located as follows: (1) set a ruler on its long edge on a table and (2) lay the car on the ruler as shown in Figure 4. Move the car forward or backward until it balances on the ruler. This balance point is the center of gravity.

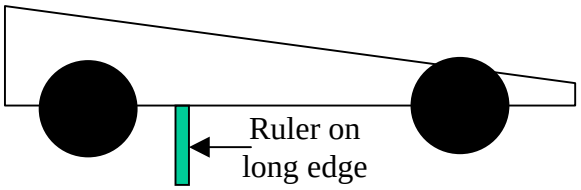


FIGURE 4
Locating the Center of Gravity

[3]The center of gravity is the point at which the car is perfectly balanced in all three dimensions (length, width, and height). For a reasonably symmetrical Pinewood Derby car, the width location of the center of gravity is not important, the height location is marginally important, while the length location has the greatest affect on the speed of the car.

Wheel Preparation

There are four steps to preparing wheels: Smoothing, Grooving, Coning, and Raising. The Smoothing step should always be performed. The other three steps are less important, and require careful work with a sharp knife.

Smoothing

The wheels supplied with the car kit are not perfectly smooth (prove this by rolling a wheel across a smooth kitchen countertop), and may have molding spikes and burrs. By smoothing the wheels, the speed of your car will improve.

> ### *Caution!*
> ***Adult supervision is required for this task.*** Use caution to ensure that loose clothing or hair does not get anywhere near the revolving drill, or a serious injury could occur. **Always wear eye protection!**

1. Remove all burrs and molding marks from the wheels (see Figure 5). An Exacto knife makes a nice tool for removing burrs.
2. Lock an electric drill in place using a vise or clamp.
3. Place the wheel into a 'wheel mandrel' (a special tool designed to hold the wheel in the drill chuck) with hub facing outward (see Figure 6).
4. Dip a strip of 600 grit wet/dry sandpaper in water, start the drill, and touch the wheel lightly with the sandpaper. Sand the tread area, the inside edge of the wheel, and the corners of the wheel. Continue sanding until the wheel is very smooth, using additional strips of dampened sandpaper as needed.
5. Repeat for the other three wheels.

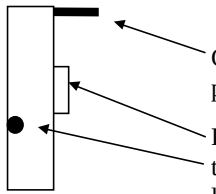


FIGURE 5
Removing Burrs

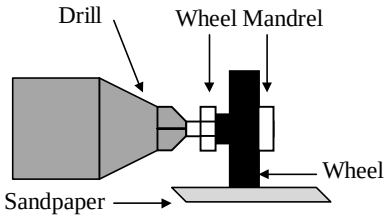


FIGURE 6
Smoothing Wheels

Grooving

Grooving refers to removing part of the wheel tread. There are several patterns that can be used (see Figure 7). The easiest pattern to implement is pattern C, as it only requires a straight cut.

A - Okay

B - Okay, but difficult to locate the ridge at the center of gravity of the wheel. If the ridge is not at the center of gravity, the wheel will tilt, causing binding between the wheel and axle.

C - Okay as long as the wheel can still stand up by itself. If the wheel is cut very thin, it will not stand up. The wheel will then tilt towards the car, causing binding between the wheel bore and axle.

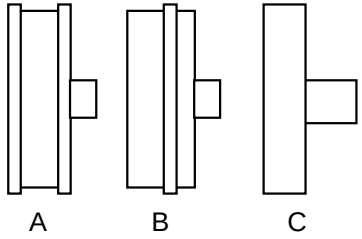


FIGURE 7
Wheel Grooving Patterns

Important!

Before cutting wheels, make sure it is allowed in your race.

Caution!

Adult supervision is required for this task. Use caution to ensure that loose clothing or hair does not get anywhere near the revolving drill, or a serious injury could occur. **Always wear eye protection!**

To create pattern A:

1. Lock an electric drill in place using a vise or clamp.
2. Attach the wheel to the chuck using a wheel mandrel.
3. Start the drill and touch the wheel *lightly* with the tip of an Exacto knife (or another cutting implement such as a lathe knife) to make two grooves about 1/32" deep (see Figure 8). Then turn the blade slightly and remove the material between the two grooves. To keep the blade and wheel cool, apply drops of water to the wheel with an eye dropper while cutting.

To create pattern B, follow the steps above, but locate the two grooves to define the ridge.

To create pattern C, follow steps 1 and 2 above, and then use the tip of an Exacto knife to *slowly* slice through the wheel at approximately the midpoint of the tread.

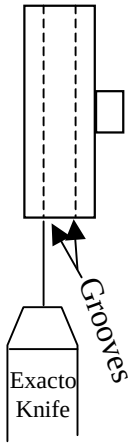


FIGURE 8
Making Grooves

Coning

Coning refers to removing material from the wheel hubs. This is accomplished by holding a wheel in one hand, and carving the hub with an Exacto knife held in the other hand (see Figure 9). If you choose to skip this step, make sure to eliminate any burrs located on the wheel hub.

Caution!

This step must be performed by an adult. Use extreme caution to avoid a serious injury.

When removing hub material, be careful to leave a small area around the axle hole intact. Otherwise, the axle hole may be damaged, eliminating any benefit from the coning operation.

Some wheel types have an outer hub. Although the operation is more tricky, coning can also be applied to the outer hub of those wheels.

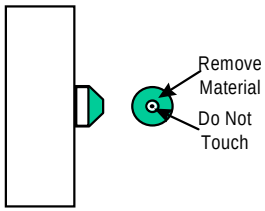


FIGURE 9
Wheel Hub Coning

Raising

Raising refers to lifting a front wheel such that only three wheels touch the track. If this technique is used, make sure that the center of gravity of the car is offset towards the back, otherwise, the car will tend to rock towards the raised wheel. Also make sure that the wheel is raised no more than 1/16" so that it can still contact the track guide rail.

Below are three ways to raise a front wheel. They are arranged from easiest to hardest.

1. Tilt the wheel/axle upwards when installing the wheel into the axle slot (see Figure 10). If the axle slot is shallow, you may need to bend the axle
2. Drill a new hole for the raised axle in a location such that when mounted, the wheel does not touch the track.
3. Reduce the wheel diameter by removing tread.

Use the poorest spinning wheel for the raised wheel. Find it by spinning each wheel and measuring the amount of time before the spinning stops. Alternately, the wheel that rolls the least straight can be mounted on the raised axle.

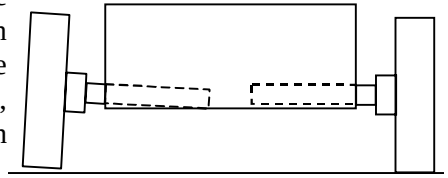


FIGURE 10
Wheel Raising

Axle Preparation

To reduce friction between the wheels and the axle, the axles must have a mirror-like finish. If your kit includes nail-type axles, both a grinding and polishing step are required. If your kit includes rod-type axles, then only a polishing step is required (see Figure 11 for axle types).

> ### *Caution!*
>
> ***Adult supervision is required for this task.*** Use caution to ensure that loose clothing or hair does not get anywhere near the revolving drill, or a serious injury could occur. During the polishing step, do not use a large cloth as the excess material could get caught in the revolving drill. **Always wear eye protection!**

Grinding Step

The purpose of the grinding step is to remove the ridge and create a taper on the head of a nail-type axle (see Figure 12). A triangular file is required for this step.

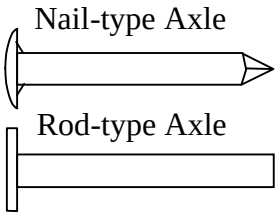


FIGURE 11
Axle Types

1. Lock an electric drill in place using a vise or clamp.
2. Place the axle in the drill chuck and tighten securely.
3. Start the drill with the axle spinning as shown in Figure 13. Use *light pressure* on a triangular file to remove the ridge near the nail head and create a slight taper on the nail head (see Figure 12).

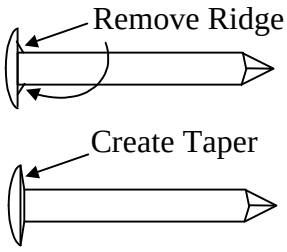


FIGURE 12
Goal of Grinding

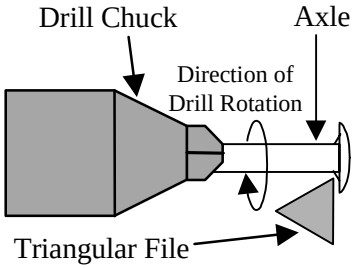


FIGURE 13
Grinding Nail-Type Axles

Polishing Step

The purpose of the polishing step is to create a shiny finish on the portion of the axle on which the wheel will spin. This area includes the inside of the axle head. Recommended polishing materials include: jeweler's rouge, pumice, Brasso (a metal polish), or an axle polishing kit (see "Specialty Tools and Supplies" on page 27).

Nail-type axles:

1. Lock an electric drill in place using a vise or clamp.
2. Place the axle in the drill chuck, tighten securely, and start the drill.
3. If the axle is scarred from the grinding step, start with a strip of 400 grit wet/dry paper. Dip the paper in water and sand the nail and the inside of the nail head (see Figure 14).
4. Switch to a strip of dampened 600 grit wet/dry sandpaper. Again, make sure to sand the inside of the nail head.
5. Repeat with a second strip of dampened 600 grit wet/dry sandpaper.
6. Apply a small amount of the polishing material to a small piece of soft cloth.
7. Touch the cloth to the portion of the axle on which the wheel will spin (see Figure 15). Polish until the axle has a shiny finish (about 30 seconds). Make sure to polish the inside portion of the axle head.
6. Remove all polishing compound using a clean, soft cloth.

Rod-type axles:

Perform the steps listed above, but skip steps 3 to 5.

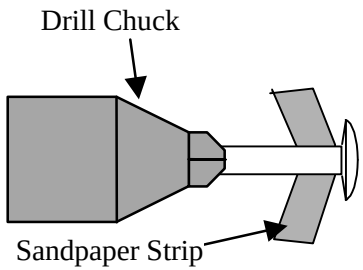


FIGURE 14
Sanding the Axle

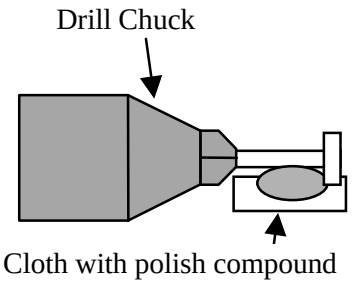


FIGURE 15
Polishing the Axle

Lubrication

Before attaching the wheels and axles to the car, apply a lubricant to all friction points. Many different lubricants have been successfully used, however, the most widely (and successfully) used is a graphite/molybdenum compound. This type of lubricant is sold at many hobby stores under various brands. A suggested brand is "Hob-E-Lube."

Here are several tips for applying graphite:

1. Graphite is messy, so spread some paper on the work surface. Graphite also floats in the air, so wear a particle mask.
2. Before attaching the wheels to the car, apply graphite into each wheel hub, insert the axles, and then spin the wheels 10 times each, allowing the wheels to stop rotating between each spin. Repeat this process 5 times (possibly once a day for 5 days). This ensures that the graphite is fully embedded into the hub of the wheel. Once this process is started, keep each wheel/ axle pair together as a matched set.
3. Test your lubricated wheel by holding the axle level in one hand and spinning the wheel as fast as possible with the other hand. A well-lubed wheel will spin for at least 20 seconds.
4. Using a fingertip, rub a *small* amount of graphite on the car body where the wheel hubs touch the car body.
5. Using a finger tip, rub a *small* amount of graphite on the inner edge of the wheel. This will reduce friction when the inside of the wheel rubs against the track guide rail.
6. After installing the wheels, apply graphite one last time before the weigh-in.
7. ***Remove any loose graphite before turning in the car. This will help keep the staging area, track, and race officials from getting dirty (they will appreciate it!).***

Important!

Once the car is turned in at weigh-in, adjustments generally cannot be made, including adding a lubricant. Make sure you lubricate the car BEFORE THE WEIGH-IN!

Wheel Alignment

The wheels of the Pinewood Derby car must be aligned as straight as possible and the wheel-to-body clearance must be properly set to reach *Maximum Velocity!* Perform the following steps to align the wheels:

1. **Set the Wheel Clearance** - When attaching the wheels/axles adjust the wheel clearance to 1/16" to 1/32" (see Figure 16). Too wide of a clearance will cause the car to zig-zag down the track, while too narrow of a clearance will cause the wheels to constantly rub against the car.

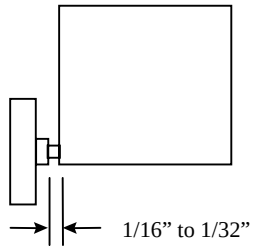


FIGURE 16
Wheel Clearance

2. **Set the Axle Height** - Set the axle height by placing the car on a flat surface such as a kitchen countertop. Use a ruler to measure the distance from the countertop to the bottom edge of each corner of the car. Adjust each axle up or down in the axle slot until the four corners of the car are the same height above the counter top and all four wheels touch the surface at the same time (see Figures 17). If one of the front wheels has been purposely raised, then of course only three wheels will touch the surface.

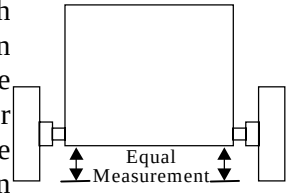


FIGURE 17
Axle Height

3. **Wheel Angle** - Adjust each wheel so that it is straight up and down, not an an angle (see Figures 18 and 19).
4. **Testing the Car Alignment** - Attach a piece of masking tape (3' to 4' long) to a smooth, level surface. Use a straightedge to make sure the tape is straight. Set the car on the surface, straddling and aligned with the tape. Roll the car on the surface using the tape as a guide. The car should be able to roll 3' to 4' with little to no deviation from its course. If the car does not stay straight within that distance, an adjustment must be made.

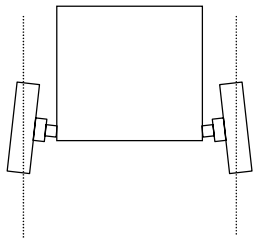


FIGURE 18
Incorrect Angle

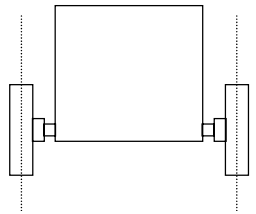


FIGURE 19
Correct Angle

5. **Adjusting the Alignment** - To adjust the wheel alignment, remove one of the front axles/wheels. If one of the wheels is raised, remove the wheel/axle which touches the ground.

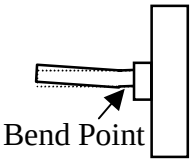


FIGURE 20
Axle Bend Point

Using pliers, or a vise and pliers, *slightly* bend the axle at a location 1/16" beyond the hub of the wheel (see Figure 20). Be careful to not scar the portion of the axle on which the wheel rides. Reinsert the axle/wheel into the car, and repeat steps 1 to 4.

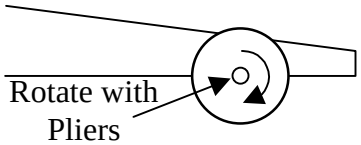


FIGURE 21
Rotating the axle

Using a pair of pliers, grasp the head of the bent axle and rotate it slightly (see Figure 21). Then retest the wheel alignment.

Continue rotating the axle and testing the alignment until the car rolls straight.

Additional Speed Tips

Here is a collection of additional speed tips. The speed tips we have tried are in **bold** type. The others we have not tried and thus we cannot attest to their benefit.

Body

1. **Wood Block Baking** - The intent of this step is to remove fluid weight from the wood block, thus allowing the addition of more lead at the rear of the car. If the wood block has been properly dried, or if you live in a dry climate, baking the wood block will have virtually no affect on the weight of the block. However, if you live in a damp climate, this step might be useful. If you choose to bake the block, put the wood block on a middle oven rack, set the oven temperature to 325º, and bake for 2-4 hours *before you do any work on the body*.

2. Body Shape - The body can be shaped such that it allows the car to start rolling before the starting gate is fully retracted. This gives the car a fraction of a second head start over other cars (see Figure 22). The disadvantage to this technique is that the car has an oddly shaped front end.

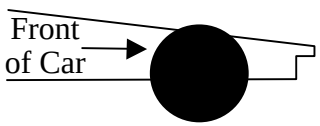


FIGURE 22
Body Shape Advantage

Axles

3. **Axle Grooving** - Before polishing the axles, a groove can be cut into the axle with a file (see Figure 23). The intent of the groove is to reduce the surface area contact between the axle and wheel bore (thus reducing friction) and to provide a reservoir for graphite.

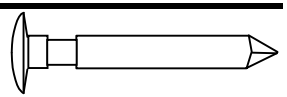


FIGURE 23
Axle Grooving

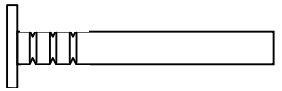


FIGURE 24
Axle Grooving - Alternative Method

An alternate way to groove the axle is to create several small grooves (see Figure 24). In either case, care must be taken such that the groove(s) is positioned on the portion of the axle on which the wheel bore will spin, and the groove(s) must not extend beyond the wheel bore. *Use care, as this step may bend the axle or cause the axle to become weak.*

4. **Axle Diameter Reduction** - Before polishing the axles, the diameter of the axle can be reduced with a file. The intent of reducing the diameter is to reduce the contact area between the wheel bore and axle, thus reducing friction. This will cause the wheels to fit more loosely on the axles, with uncertain results. Use care, as this step may bend the axle or cause the axle to become weak.

5. **Axle Hardening** - To prevent the graphite from scratching the polished axle, harden the axles by holding them in the flame of a propane torch until red hot, and then dropping then in water. The finish on the axles will then need to be restored by following the steps on page 14 (nail-type axles).

Wheels

6. **Bore Polishing** - The wheel bore is generally not perfectly smooth, so polishing the wheel bore should reduce friction by lowering the coefficient of friction. To polish the bore, insert a short piece of pipe cleaner into the chuck of a drill, apply graphite to the pipe cleaner, slide the wheel onto the pipe cleaner, then start the drill while holding the wheel. After a few seconds of polishing, stop the drill. Repeat the process about 3 times for each wheel.

7. Hub Caps - If your wheels are solid from the tread to the bore (no spokes), then after inserting the axle, you can use a round sticker to cover the outer portion of the wheel (see Figure 25).

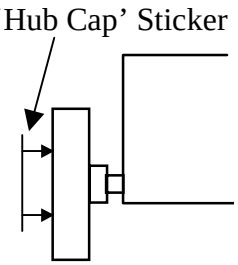


FIGURE 25
"Hub Caps"

This 'hub cap' may act as a reservoir for graphite. Since the hub cap will stop the wheel from moving away from the axle head , it may prevent the wheel from contacting the body. On the other hand, the hub cap will rub on the axle head. Assuming that the sticky part of the hub cap is well coated with graphite, this should be better than the wheel contacting the body.

8. Wheel Letter Removal - The intent of this step is to sand off the raised letters on the wheels. This would provide no aerodynamic benefit, however, it would slightly reduce the weight of the wheels, thus reducing rotational inertia. On the other hand, since most races require the use of the supplied wheels, removing the letters could raise a question at the weigh-in as to the wheel type.

9. **Drilled Side Walls** - For wheels with solid side walls, weight can be removed from the wheel by drilling holes through the side walls. Make sure that the holes are drilled symmetrically and the same number of holes are drilled on each wheel.

Lubrication

10. **Thin-Film Lubricants** - Some people have reported good success using thin-film lubricants instead of graphite. These lubricants generally contain silicon or Teflon, and are very light weight. Be careful to not apply to much, as the excess could get on the track. Also, many races have rules on the type of lubricants that can be applied, so make sure you check the rules before applying a non-graphite lubricant.

Weighting

11. **Over-weighting** - Most scales used at weigh-ins are accurate to 1/10th of an ounce with rounding. Thus, if a car weighs between 5.01 and 5.04, it will register as 5.0 ounces, and if the car weighs between 5.05 and 5.09, it will register as 5.1 ounces. Thus, when building a car add enough weight so that it weighs at least 5.1 ounces. Then at the weigh-in, remove a small amount of weight at a time until the car registers as 5.0 ounces.

Track Placement

12. **Aligning** - Many races allow the car owner to place the car on the track. When placing the car, make sure that the car is evenly centered over the guide rail, and pull all four wheels away from the body (there is less friction between the axle head and the wheel hub than between the car body and the wheel hub.

Techniques to Avoid

Over the past several years I have read a large amount of information on Pinewood Derby racing. Occasionally, I find a 'gem' of information which I then add to this booklet. But I also run across some ideas which range from useless to counter-productive. So in order to provide you with the most complete source of information, I am including several 'techniques' which I council you to avoid.

Wheel Treatments

1. **Wafer Thin Wheels** - Figure 7c on page 11 shows the profile of a narrow wheel. Obviously, the wheel could be cut narrower. However, if the wheel is too narrow, it will no longer stand upright. Thus, when attached to the car, the wheel will tilt towards the car. This tilting causes the axle and wheel hub to bind, reducing the speed of the car. Thus, if you narrow the wheels, make sure that the wheels can still stand upright.

2. **Tilted Wheels** - Some people advocate tilting the wheels towards the car. Their rationale is that (1) the wheels will stay towards the axle heads and thus not rub on the car, and (2) the wheels will ride on the inner edge, thus reducing wheel to track contact. This is all true, however, the tilting will cause a significant binding between the axles and wheel hubs, completely counteracting any advantage.

3. **Turned Front Wheel** - Believe it or not, a commercial booklet available on the Internet instructs the car builder to turn one of the front wheels inward so that the car rubs against the center guide all the way down the track. Allegedly, this is better than the car bumping the center rail a few times. This technique is easily proven wrong by time trials (see "Axle Alignment" on page 22

Lubrication Methods

4. **Graphite Bath** - Many people recommend putting the wheels and axles in a bag of graphite for several days. While this may work, it is very messy. Instead, put the graphite at the friction points (would you lubricate your automobile by dipping the entire wheel and axle assembly in to a big container of grease?). You will save graphite, have less of a mess, and the track officials will thank you.

5. **White Teflon** - Don't use it unless required by your race rules. It is almost worse than racing with no lubricant.

Time Schedule

In order to create a car that reaches *Maximum Velocity*, you must put in the time and effort. Here is a simple schedule to help you plan the creation of a high-performance Pinewood Derby car. Note that the times are based on a relatively simple car design, availability of basic tools, and a reasonable familiarity with using the tools. If these assumptions are not true, then the duration of the tasks will be longer than shown.

If the Race is 4 Weeks Away:

Week #	Activity	Duration
1	1. Read this entire booklet 2. Design the car 3. Purchase needed materials 4. Measure and rough cut the block	1 hour 1 hour 1 hour 30 minutes
2	1. Shape and sand the block 2. Apply first coat of paint/primer to the car 3. After the paint is dry, re-sand the car, and apply a coat of paint 4. After the paint is dry, repeat previous step if needed 5. Attach weights to car 6. Apply finish trim (if any) and numbers to car	2 hours 15 minutes 30 minutes 30 minutes 30 minutes 30 minutes
3	1. Polish the Axles 2. Prepare Wheels	1 hour 1-3 hours
4	1. Lubricate wheels/axles (including spinning and reapplying lubrication) 2. Attach wheels and align 3. Glue axles to body 4. Store until race	1 hour 1-2 hours 15 minutes

If the Race is 2 Weeks Away:

Complete the activities for weeks 1 and 2 above in the first week, and the activities for weeks 3 and 4 in the second week.

Time Trials

Time trials were performed to determine how much benefit comes from the various techniques. To gather the information, two identical cars were built such that the amount of weight and weight location could be easily changed on each car. Also, the wheels/axles could be easily changed. Note that these tests were performed on a ramp-and-flat track.

For all of the tests below, Car #1 was consistently equipped with:

- Weight to bring the car to 5 ounces, and the center of gravity at 1" in front of the rear axle
- Standard wheels with graphite lubrication
- Four properly aligned wheels on the ground

Car #2 was identically equipped except as noted below.

Weight

For this test, first 1/2 ounce and then 1 ounce of weight was removed from Car #2:

- With 1/2 ounce missing, Car #2 lost by 3"
- With 1 ounce missing, Car #2 lost by 6"

Weight Location

For this test the weight on Car #2 was moved to the front of the car, and then to the middle of the car:

- With the weight in front, Car #2 lost by 9"
- With the weight in the middle, Car #2 lost by 5"

Lubrication

For this test Car #2 was equipped with wheels that had no lubrication, and then with silicon oil lubricated wheels:

- With non-lubricated wheels, Car #2 lost by 15"
- With silicon oil lubricated wheels, Car #2 lost by 2"

Axle Alignment

For this test Car #2 was equipped with a bent axle, causing a front wheel to point inward:

- Car #2 lost by 7"

Narrow Wheels

For this test Car #2 was equipped with narrow wheels (*see pattern C under Grooving on Page 11*):

- Car #2 won by 2"

Lifted Wheel

For this test Car #2 was equipped with a lifted wheel:

- Car #2 won by less than 1"

Science Background

This section provides information as to why particular techniques increase the performance of a car. If you are interested in further information, specifically the mathematical basis for the techniques, please visit: *www.worldforchrist.org/races/cars.*

Adding Weight

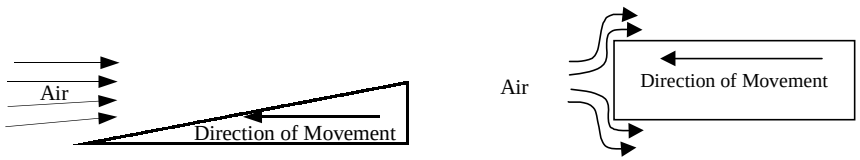
The weight of the car provides two benefits: (1) When the starting gate drops, the weight serves as a source of energy to start the wheels spinning, thus, overcoming the rotational inertia of the wheels, and (2) When the car reaches the flat part of the track, the weight increases the momentum of the car, thus, keeping the car rolling at top speed for a longer period of time.

Thus, given two identical cars, except that one is heavier than the other, the heavier car will reach the flat part of the track slightly earlier than the lighter car. In addition, the lighter car will slow down more quickly, allowing the heavier car to win.

Aerodynamics

Aerodynamics refers to the way in which air is moved by an object. An object with good aerodynamics moves very little air, and is thus only slightly slowed down by the air. On the other hand, an object with poor aerodynamics moves a lot of air, and is greatly affected by the air (see Figure S1).

Just like a real automobile, a Pinewood Derby car should be designed to move as little air as possible as it rolls down the track. Given two cars with identical characteristics except that one car has good aerodynamics, while the other has poor aerodynamics, the car with good aerodynamics will have a slight advantage.



Good Aerodynamics
(*Little air will be moved*)

Poor Aerodynamics
(A *lot of air will be moved*)

FIGURE S1
Aerodynamics

Axle Preparation

Friction is the force that slows down your car. It is the #1 enemy! Friction is defined as the weight of the object multiplied by the 'coefficient of friction'. The coefficient of friction is a measure of the 'slickness' of an object, and it varies by the type of material. The coefficient of friction can be reduced by smoothing the object, and by applying a lubricant. The axle preparation step reduces friction by smoothing the surface of the axle.

Lubrication

As mentioned above, friction is the force that slows down the car. The coefficient of friction can be reduced by applying a lubricant. The lower coefficient of friction allows the car to maintain speed for a longer period of time.

Positioning Weight

The speed of the car at the beginning of the flat part of the track is based (among other factors) on the distance that the center of gravity of the car traveled. Given two identical cars, except that the center of gravity of one car is further towards the rear, that car will have traveled a greater distance, thus, it will have achieved a higher speed. Why is this?

While a car is rolling down the slope, it is accelerating. Assuming that the car is well aligned and lubed, it will accelerate until it reaches the flat part of the track. The car that has the longest acceleration time will attain the greatest speed. Referring to Figure S2, the center of gravity for car B will travel a greater distance than the center of gravity for car A, thus car B will have a greater velocity when the cars reach the flat part of the track.

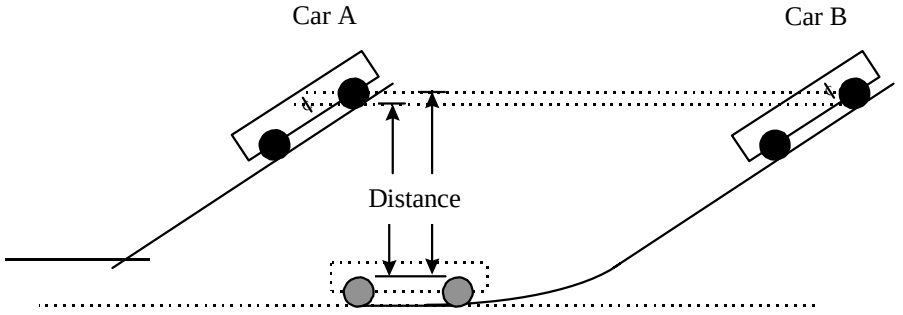


FIGURE S2
Effect of Center of Gravity Location on Distance

Wheel Preparation

Each of the four wheel preparation steps (Smoothing, Grooving, Coning, and Raising) improves the rolling ability of the car in a different way.

Smoothing - The smoothing step removes flaws on the wheels, thus allowing the wheels to roll smoother and straighter. Thus, it reduces the wheel to track friction.

Grooving - Grooving involves two principles: reducing the amount of contact between the track and wheels, and reducing rotational inertia.

1. Reducing the amount of surface contact serves to reduce the effect of track imperfections on the rolling car. By reducing the amount of track contact, fewer of the track imperfections affect the car. Reducing the surface contact does not reduce friction, as the frictional loss of a rolling object is independent of the amount of contact area (F = Mass x Gravity x Coefficient of Friction).
2. Rotational inertia refers to the amount of energy required to start a wheel spinning, and is dependent on the configuration of the wheel. The most efficient (least inertia) wheel is a flying saucer shaped wheel, thicker in the middle, and tapering to nothing at the edges. The least efficient wheel is a hollow ring. Grooving removes plastic at the least efficient area (the outer edge of the wheel), thus reducing the rotational inertia and reducing the amount of energy required to spin the wheels up to speed.

Coning - Coning reduces the braking-effect caused by the hub rubbing on the body of the car. By coning the hub, the amount of contact area is reduced, and the contact area is concentrated near the axle where it has the least effect on the car.

Raising - Raising one front wheel provides three benefits:

1. Some frictional loss is eliminated since the raised wheel does not spin. Note that wheel to track friction is transferred to the other three wheels.
2. Wheel alignment is simplified. The raised wheel does not need to be aligned.
3. Since only three wheels must start rolling, rotational inertia is reduced by 25 percent.

Web Sites

Here are some of the better Pinewood Derby-oriented web sites. Note that some of the information provided at these sites conflicts with the information contained in this booklet. As in all of life opinions vary, and sometimes these opinions are not based on truth. Thus, these sites (as well as this booklet) should be read with the brain engaged.

Supplies

Rockler Woodworking and Hardware - Mail order supplier of woodworking supplies.
www.rockler.com

Tips, etc.

Grand Prix Race Central - Includes race mangement information, tips, and much more.
grandprix-race-central.com/

Hobby Science Manuals - A car building guide with extensive information on the science principles involved in Pinewood Derby racing.
www.worldforchrist.org/races/cars

Pinewood Derby Car Building Tips - Includes tool tips, site reviews, and what to do when you go 'woops'.
www.maximumvelocity.com

Pinewood Derby Mania! - General information site.
www.geocities.com/Yosemite/9152/pinewood.html

The Pack 146 Pinewood Derby - Includes experiments with different car configurations
www.geocities.com/Yosemite/Rapids/7146/pinewood.html

And don't forget to subscribe to our e-newsletter, the
Pinewood Derby Times
at
www.maximum-velocity.com/subscribe.htm

Specialty Tools and Supplies

Specialty tools and supplies can help your car reach maximum velocity. Here are our favorite products, all of which are available at the Maximum Velocity web site at: ***www.maximum-velocity.com***

Axle Polishing Kit - Take the guess work out of axle polishing! This set of industrial grade cushioned abrasive papers is designed for polishing metal to a high shine, and is thus ideal for polishing pinewood derby axles. The kit consists five papers ranging from 30 micron to 3 micron (finer than pumice). One set of axle polishing papers will polish 8 axles.

Hob-E-Lube Graphite - A top quality graphite containing molybdenum. This is the lube of choice of most pinewood derby champions.

Maximum Velocity! - The Movie - A new video that shows a boy and his dad building a pinewood derby car from start to finish. The boy performs most of the work, and the video includes the exciting race scene.

Pro-Axle Press - A precision machined device that creates absolutely straight and round nail axles, and accurately squares the axle head to the axle shaft.

Pro-Body Tool - An innovative aluminum device that allows you to drill precise guide holes into the existing axle slots, or drill new axle holes with a hand drill!

Pro-Hub - A unique tool that squares the wheel hub to the wheel bore, easily cones the inside wheel hub, and reams undersized wheel bores (great for wheels that don't fit on the mandrel!).

Solid Lead - The traditional choice for car weighting, solid lead is much denser than the zinc product sold at hobby stores, and is readily cut and shaped. Just be careful in handling as lead is toxic if taken internally. Available as a 3/8" diameter wire, or in segmented form.

Tungsten - An alternate weight, tungsten is non-toxic and much heavier than lead (weighs the same as pure gold). If you want to create a minimalist design, then tungsten is the best bet for weighting your car. Available in cylinders, cubes, beads, and disks.

Wheel Mandrel - This tool is used to mount wheels in a drill, and is an absolute must for preparing pinewood derby wheels.

About the Author

My wife and I, and our four children live in the greater Phoenix area (it's a dry heat!). My entire family is involved in the Awana[4] program at our local church.

Seven years ago, we began participating in the Awana Pinewood Derby (known as the Awana Grand Prix). Then five years ago, I began leading the derby, and began studying Pinewood Derby techniques. In a desire to improve the competition by making the techniques known to all the entrants, I wrote the first edition of this booklet. For the past four years, the booklet has been distributed with the car kits at our local race. With the fourth edition, I began offering the booklet for sale outside of our local club.

My desire is that by using this booklet, not only will you create a competitive car, but that you and your parent (or mentor) will more thoroughly enjoy the car building process. Winning the race may be the goal, but much of the enjoyment of the Pinewood Derby is in creating a car that you designed.

I would greatly appreciate any feedback as to how to make this booklet more useful to you. I would also like to hear about the result of your races. You can reach me by e-mail at:

info@maximum-velocity.com

Good luck in your races, and may God bless you and your family!

Randy Davis

[4]Awana (Approved Workmen Are Not Ashamed) is a Bible-based club which began in 1950 and now has 9,500 clubs world-wide. The purpose of the club is to evangelize, challenge, and train the youth of the world to serve God. For more information on Awana, visit: *www.awana.org*.