



HOW TO BUILD A FAST PINEWOOD DERBY CAR

Scotten W. Jones

I have to do what!

Turn this



Start with the official BSA
pinewood derby car kit

Into this



Finish with a fast pinewood
derby car

Warning/disclaimer

- Building a pinewood derby car requires tools, possibly including power tools.
- Your son should be as involved in building the car as possible but you need to use good judgment in terms of what he can safely do.
- Do not let your son use tools he isn't ready to use safely. You will likely have to do some of the work yourself.
- Wear appropriate safety gear at all times.
- Each boy is different, only you know what your son can safely do.

Why listen to me

- Physicist with almost 30 years of engineering experience.
- Bought and read all the guides.
- Searched the internet and read hundreds of articles.
- Built and tested 37 cars on our own track with ten thousandth of a second timing.
- Wrote a computer simulator and tested out ideas.
- First place pack fifty, four of the last four years.
- 2006 my son was winning districts until his car was smashed, 2007 and 2008 he won districts. 2009 no district race was held, third at council.

What to do when something goes wrong

- Race long enough and you will see something go wrong.
- The races are run by volunteers doing their best for free, not paid professionals. They are trying to be fair but mistakes happen.
- I have seen:
 - Our car smashed
 - The track contaminated
 - Cars fly off the track and or handled roughly
 - Our car raced in the wrong lane and our first place credited to someone else
- Politely and privately bring up your concerns to the race officials.
- The race officials decisions are final, my experience is they will fix what they can if they understand the issue.



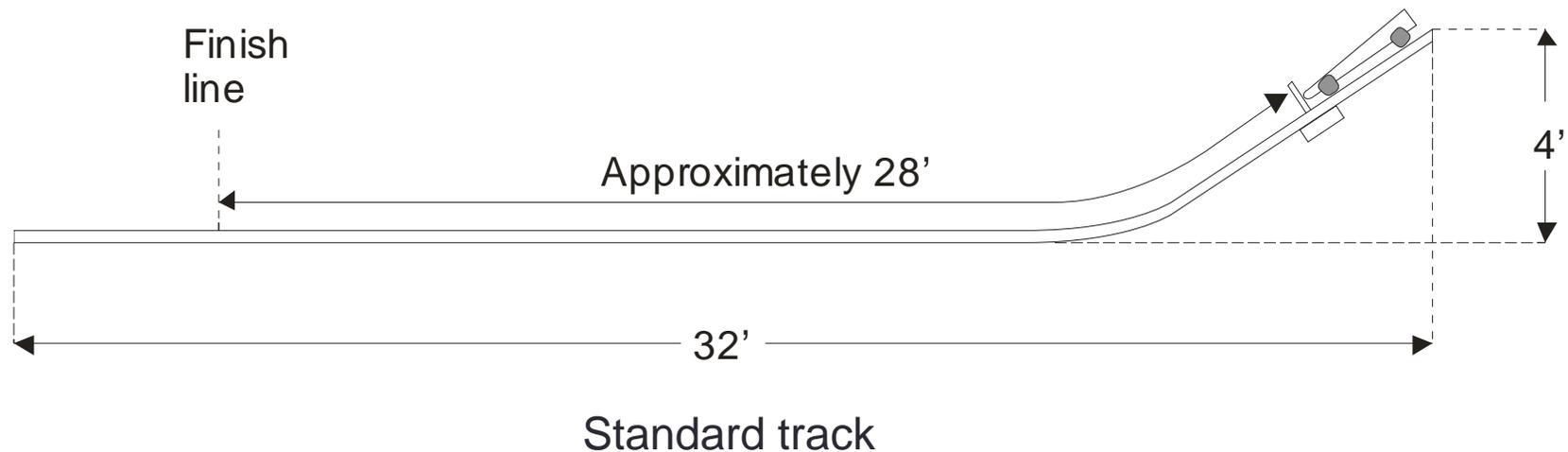
BASICS

Basic rules

- Read the official pack rules, they are final. This is just a sampling.
- Car must be built during the scouting year.
- Must use the BSA block of wood, axles (nails) and wheels.
- You cannot move the pre cut axle slots in the wood block (this is a common reason for not being allowed to race).
- The inspector must be able to see the nail points in the axle slots (another common problem area).
- Must be less than 7" long, less than 2-3/4" wide and less than 5 ounces.
- Wheel treatment has specific limits (more later)
- You can add weights but they must be secure.

The track

- The old “standard” for a track was 32’ long made of wood.
- Even years ago there was no real “standard”.
- Pack fifty uses a 40’ wooden track and has for at least ten years.
- Districts used to use 32’ wooden tracks (until 2007), now they are using 40’ aluminum tracks.

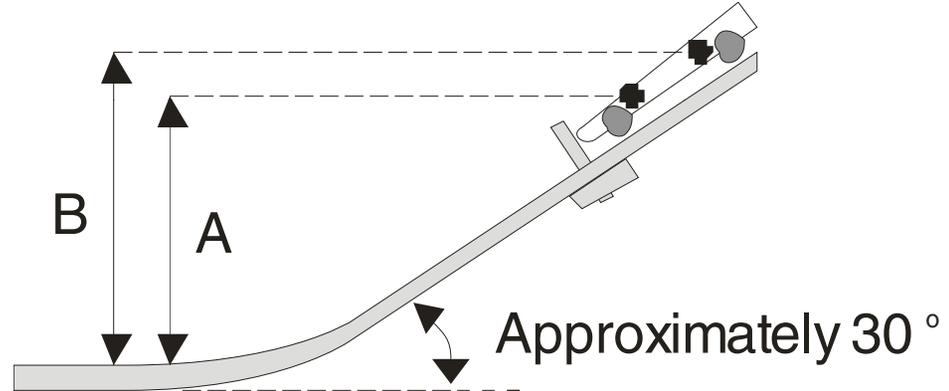


Physics (gasp)

- At the beginning of the race the car has potential energy.
 - This is the most energy the car will ever have!
- Once the starting gate opens the potential energy begins to convert to kinetic energy (speed) and heat due to friction.
- Heat due to friction is energy lost (bad) and no longer available.
- Maximize the potential energy and minimize the friction is all you have to do to make a fast car.
- Sounds simple, right?

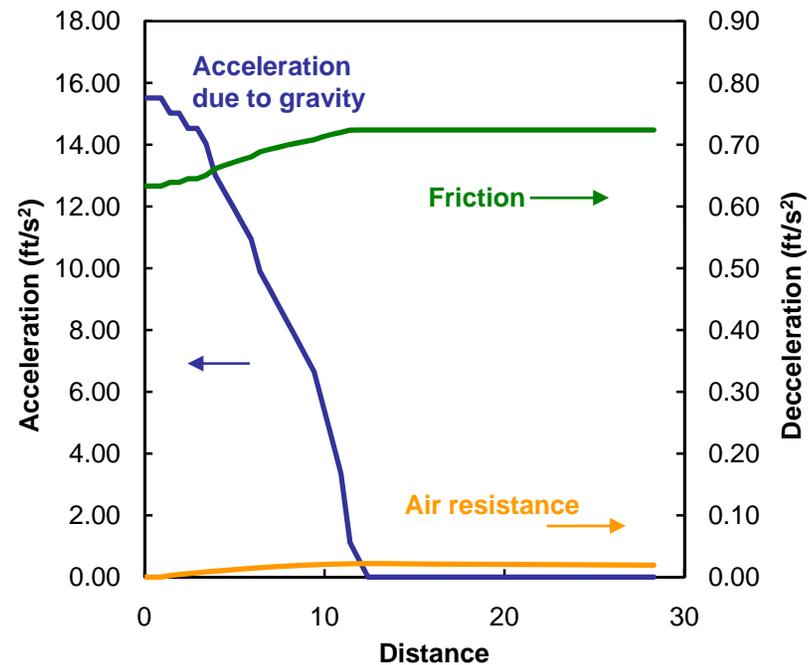
Potential energy

- Potential energy is determined by two things:
- The weight of the car.
- How far the center of gravity will fall.
- The heavier the car and the farther the center of gravity will fall the higher the potential energy.



Kinetic energy

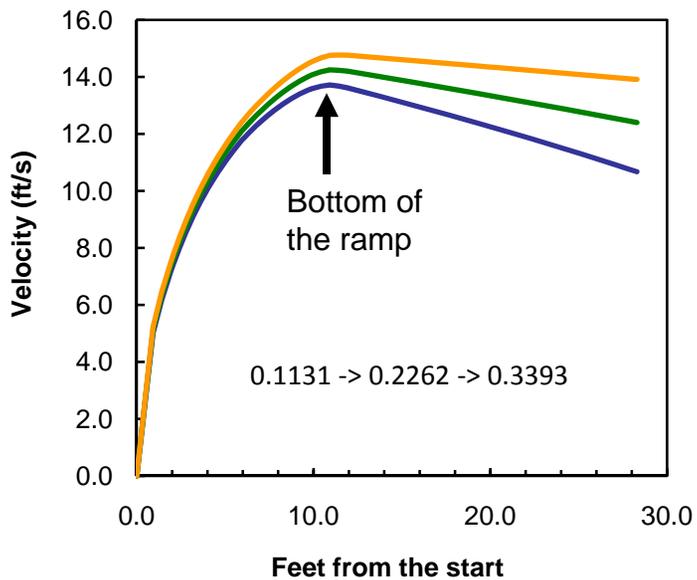
- Kinetic energy for a given weight is proportional to speed.
- Without friction 100% of the potential energy will be converted to kinetic energy as the car accelerates down the ramp.



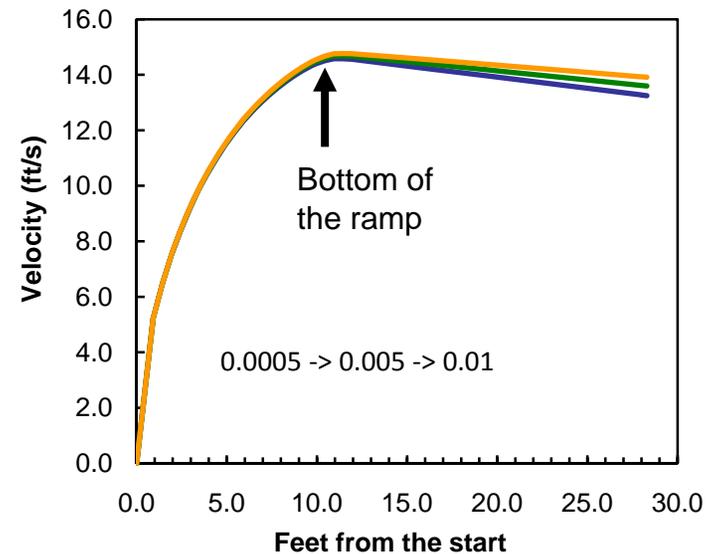
Forces acting on a well designed car.

Friction

- Rolling resistance due to wheel and axle friction is the most important effect. It effects the car during the whole race.
- Air resistance is less important and mostly effects the car once it reaches top speed at the bottom of the ramp, but it does matter.



Rolling resistance



Air resistance

The three things that matter

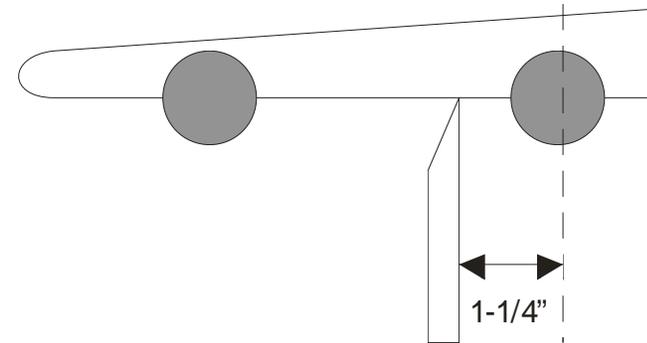
- **Weight and weight distribution**
 - **Rolling resistance**
 - **Aerodynamics**
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- Do these three things well and you will have a fast car.
 - The rest of this presentation will cover practical ways to do accomplish these three goals.



WEIGHT AND WEIGHT DISTRIBUTION

Center of gravity

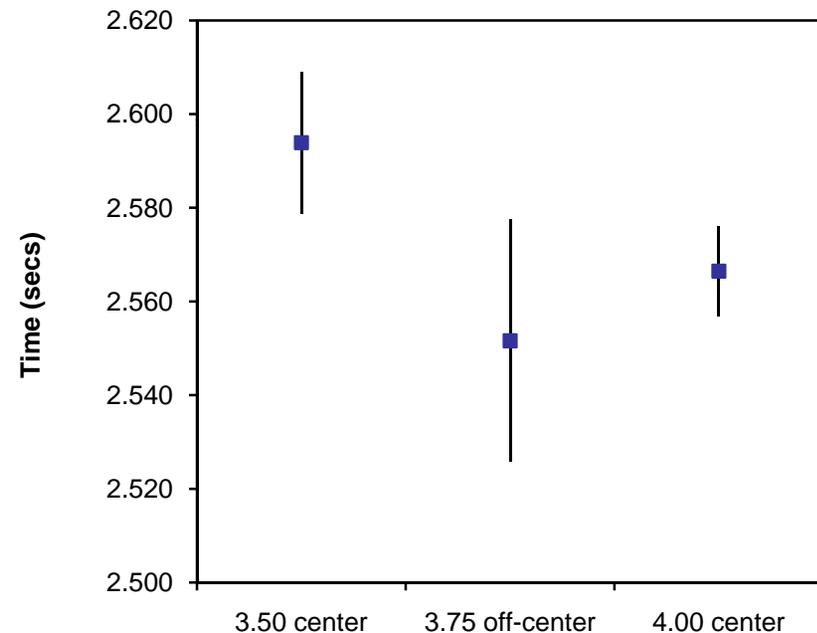
- Put the center of gravity as far back as possible so it falls as far as possible, but too far back and the front end comes off the track.
- Balance the car on a sharp edge to determine the center of gravity. You want it to balance 1-1/4" in front of the rear axle.
- The Cub Scout block of wood has one axle slots closer to the end of the car, make that the back.



Center of gravity

- Some testing I have done indicates the car is faster if the weight is more to one side than the other.
- I don't understand why this would help.
- It could be bad test data but....

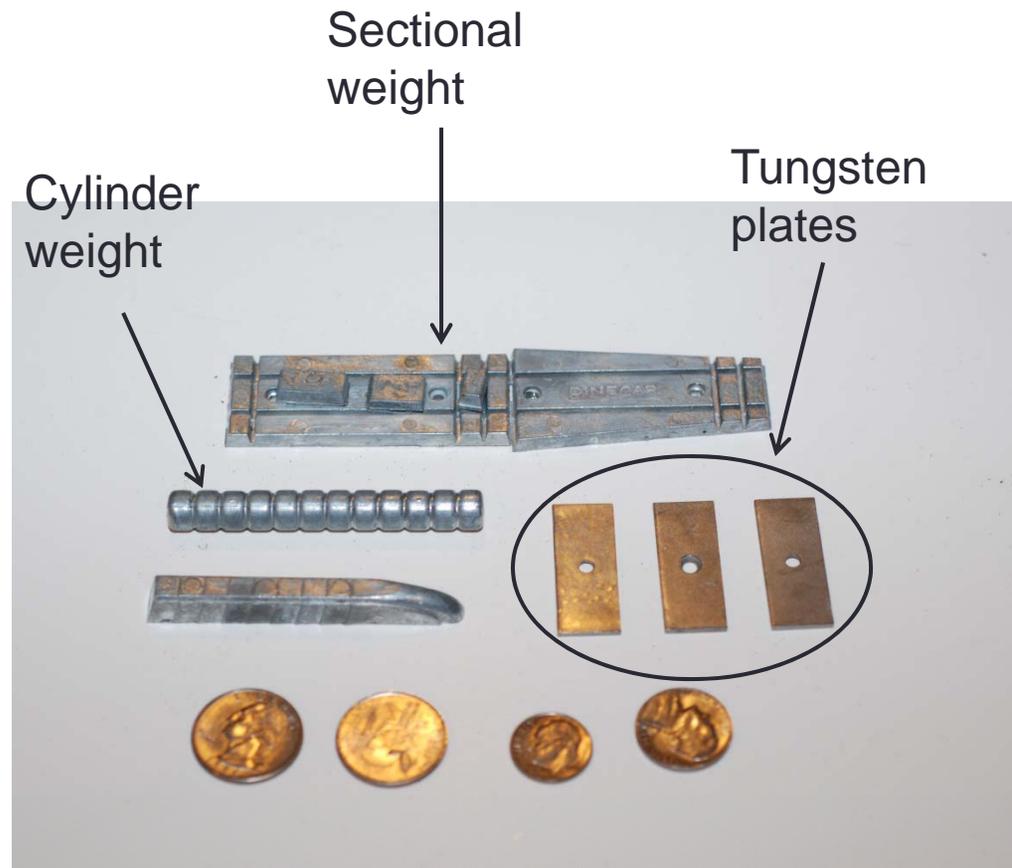
Elapsed time versus center of mass (side-to-side)



The number is weight in ounces

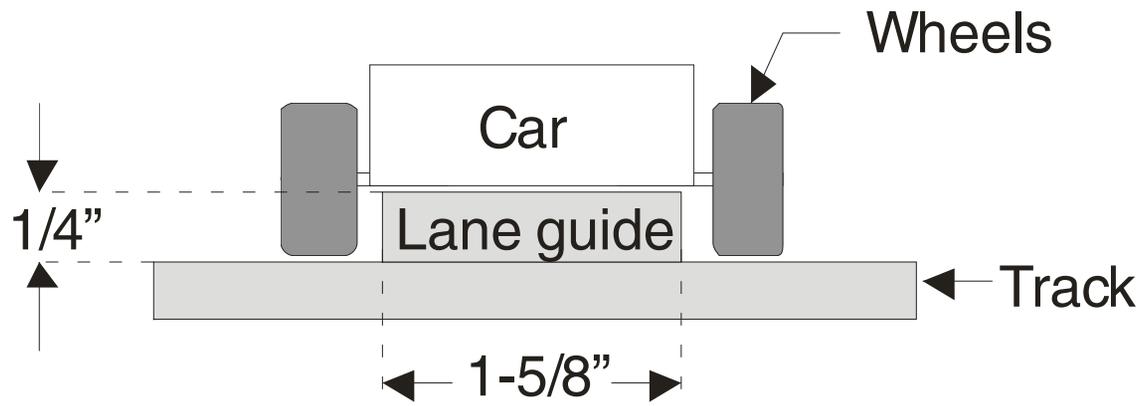
Weights

- The maximum allowable car weight is 5 ounces.
- Weights can be built into the body or added on later, internal is better for aerodynamics.
- Some people use the sectional weights on the top or bottom of a car. This is easy to do but not very aerodynamic. If the weight is on the bottom make sure it doesn't hang down too far.



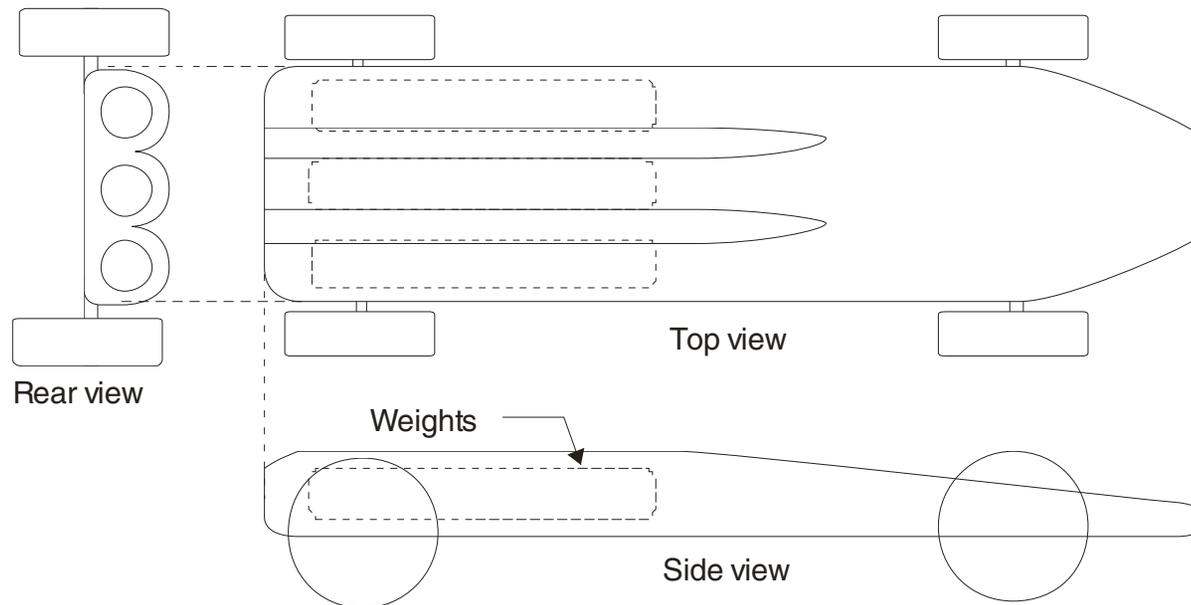
Clearing the track

- The car sits over a 1-5/8" wide by 1/4" high lane guide, you must leave enough clearance.
- Extra space is needed for the curved section of the track.



Design with weights

- This design uses the cylinder weights inserted into 3/8" holes 3" deep.
- The weight has to be filed down to fit and slides in tight allowing you to push it in until you get the center of gravity you want.



Tungsten plates

- Tungsten is more dense than lead and thin plates can be used to make a very thin car.
- You can't cut the weights and so you have to snap them off in a vise with a hammer if you need fractional plates.

Chiseling out space for the plates



The finished car





AXLES AND WHEELS

Axles as received

- Ridges and roughness.
- You must smooth out the axles for a competitive car.

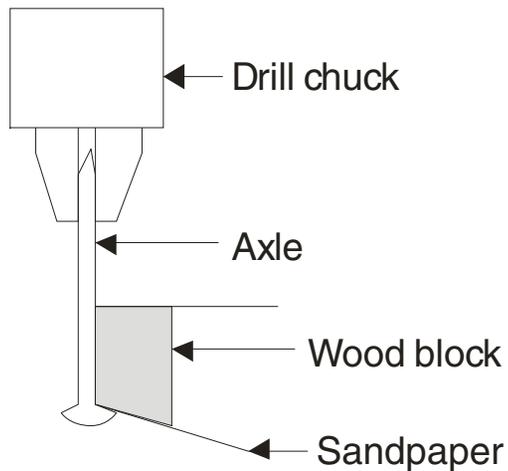
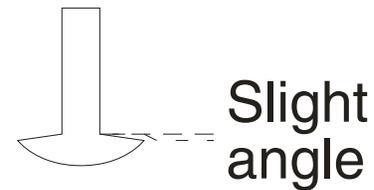


Smoothing the axle

- Mount the axle in a drill or drill press, start the axle spinning and use a fine file to remove the ridges.
- I use Maximum Velocities Axle Polishing kit to polish the axle.
- Wet the sandpaper with WD40, wrap the sand paper around a wooden block and hold against the spinning axle.
 - 30 seconds using 30 micron paper, buff with a clean cloth to remove the grit.
 - 30 seconds using 15 micron paper, buff with a clean cloth to remove the grit.
 - 30 seconds using 8 micron paper, buff with a clean cloth to remove the grit.
 - 30 seconds using 5 micron paper, buff with a clean cloth to remove the grit.
 - 30 seconds using 3 micron paper, buff with a clean cloth to remove the grit.
 - 30 seconds using Mother's aluminum polish on a cloth, buff with a clean cloth to remove the grit.
- The axle should look like a mirror.

Advanced axle preparation

- Angle the axle head so it only contact the wheel close to the center.
- Use an angled piece of wood during polishing to polis the angle.



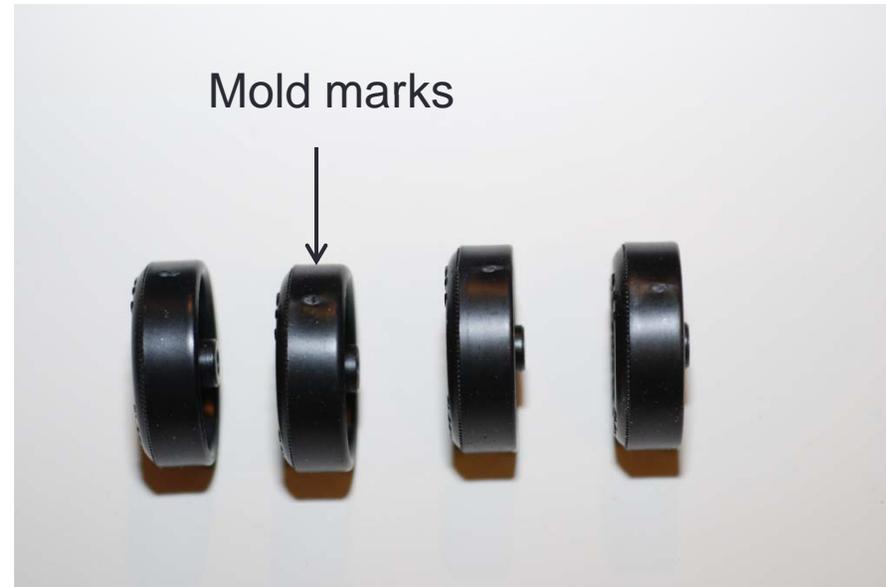
Other axle preparation options

- Axle press to insure it is straight.
- New axle press allows the head to be angled but I don't like the shape of the head that results.
- Harden the axle before polishing
 - Heat the axle up until cherry red
 - Plunge it into cold water

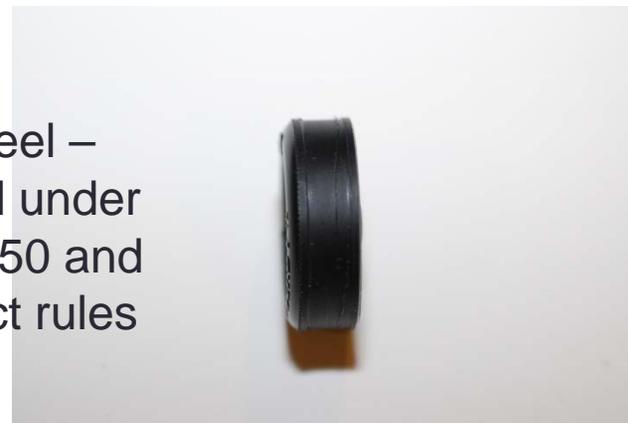


Wheel preparation

- Wheels as received have mold marks that need to be removed.
- The dots on the edge of the wheel must be left so don't remove too much material.
- The wheel tread must remain flat and cannot be narrowed.

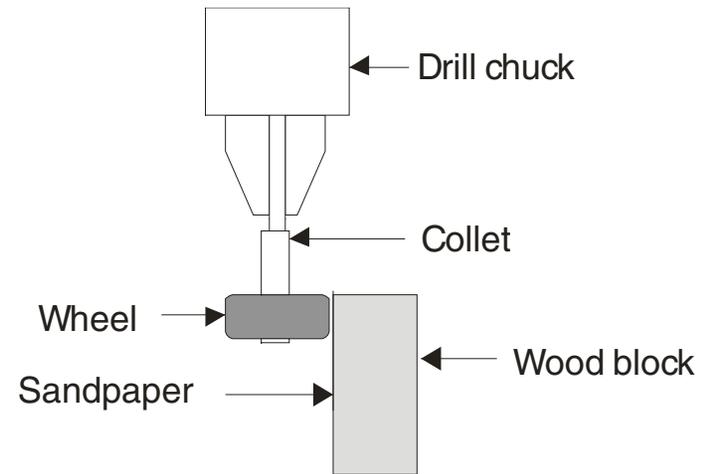


H wheel –
illegal under
pack 50 and
district rules



Wheels and wheel preparation

- Mount the wheel in a Maximum Velocity pro wheel mandrel.
- Start the wheel spinning in a drill or drill press.
- Wrap the sandpaper around a wooden block and hold against the wheel.
- Use 60 grit paper to sand out mold marks.
- Polish the wheel with 600 grit, 1000 grit and 1500 grit sand paper in sequence. The paper should be wet with water before polishing the wheel



Advanced wheel preparation

- Lathing the wheel to insure it is round.
- Balancing the wheel.
- Coning the inside of the wheel hub so it only contact the body near the axle.



Lathing tool
to insure
roundness



Wheel
coning
tool

Wheel
balancing
tool



Wheel weight

- Standard wheels are approximately 0.45 ounces per set of four.
- 0.30 and 0.15 ounce Cub Scout cut down wheels are available.
- 0.15 ounce wheels don't meet the current district rules.

Wheel weight (ozs)	Car weight (ozs)	Elapsed time (secs)
0.45	5.00	2.5581
0.30	4.85	2.4772
0.15	4.70	2.4677
0.15	5.00	2.4424



0.45 untouched wheels



0.15 cut down wheels

Lubricants – there are many choices

- Oils – Krytox, Super Z and NyOil are illegal under pack and district rules.
- Only dry powder lubricants are allowed but there are still a lot of choices.



Lubrication

- Seven years of lubricant testing head to head with identical preparation.
- Shorter times are better.

Lubricant	Time (secs)
Pine Pro	2.4768
G/M	2.4834
NyOil II	2.4934
Super Z + Oil	2.4959
Max-V Lube (Preliminary ranking)	2.5137
Tube-O Lube	2.5140
Hob-E Lube Graphite	2.5222
Hob-E Lube Teflon	3.1947

- Pine Pro is the best but it is touchy. Put it on, spin it in and leave it. It is good for about 10 to 15 races before it starts to slow down!
- I put it on and run it down the track 5 times to run it in and then leave it until race day.
- Graphite lubricants generally “warm up” and get faster.

Applying lubricants

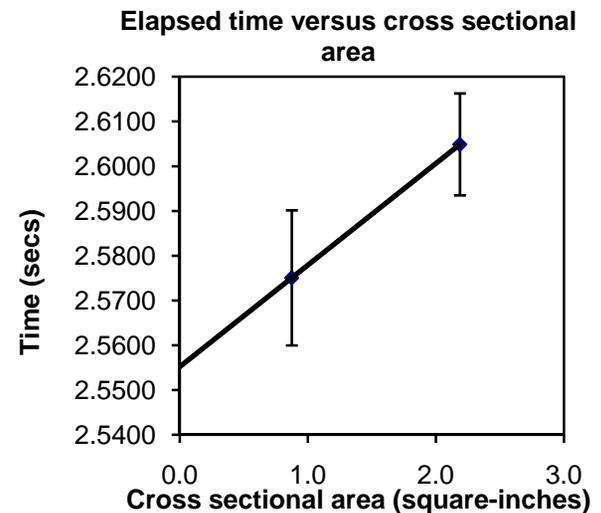
- Put some graphite on a pipe cleaner, mount it in a drill and run it inside the wheel bore to polish the bore.
 - Bore polish is available but how do you get the grit out afterwards?
- Fill the wheel bore with graphite and then slide the axle in.
- Spin the axle in the wheel bore with a drill and keep adding graphite to run it in.
- Apply graphite to the car body where the wheel will touch and on the outside and inside of the wheel where it will hit the car body and axle head.
- Mount the wheel and axle on the car, turn side ways, add graphite and spin the wheel to work it in.



AERODYNAMICS AND BODY DESIGN

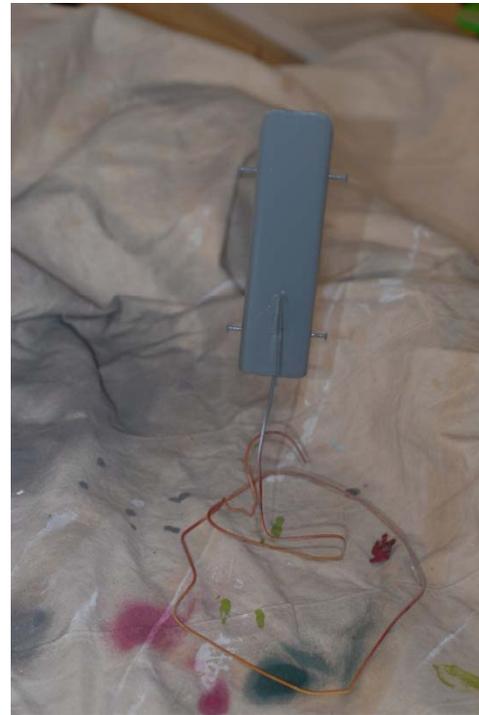
Minimize air resistance

- Minimize the car cross section in the direction of travel.
- The car surface should be as smooth and possible and taper at both ends so the air can flow smoothly over it.



Painting the car

- Put nails in the axle holes before painting to protect the slots



Faster start?

- When the starting gate opens the higher up on the pin your car hits the sooner it starts to move.
- Only matters if the gate opens slowly enough for the car to move with it.
- Beware of how the finish is judged. Some tracks use a fin that sticks up and if your front is too high you may take longer to trigger it.



Fast cars (cylinder weight)

2007 – 2.4597 average



2008 – 2.4603 average



Fast cars (tungsten weight)

2009 – 2.4654 average



2010 – 2.4537 average

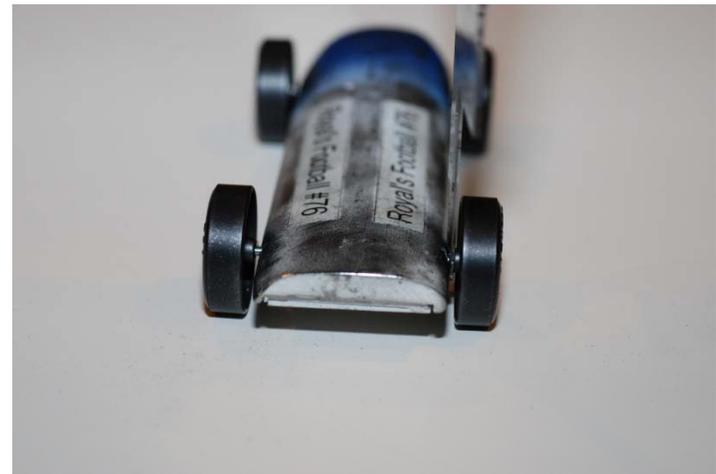




MOUNTING AND ALIGNING WHEELS

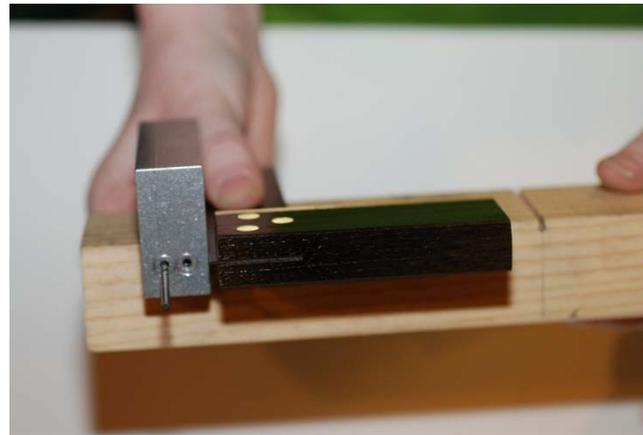
Aligning the wheels

- Use Cub Scout spacer tool to set wheel to body gap (~1/16")
- Car should not rock on a flat surface
 - “One wheel lifted is faster” is a myth based on my testing
- Roll forward and back, wheels should “track” straight and not move in or out.
- Good alignment makes a huge difference!



Alignment tools

- Maximum Velocity body tool and axle guide.
- The body tool drills out the axle slots to be perfectly square to the body.
- The axle guide helps insert the axle straight and gaps the wheel.



Pro
body
tool

Axle
guide





CONCLUSION

Conclusion

- The key items:
 - Polish the axles
 - Smooth the wheels
 - Lubrication
 - Make the car weight as close to 5 ounces as possible
 - Alignment
- Secondary items
 - Aerodynamics
 - Weight distribution

Resources

- <http://www.maximum-velocity.com/> tools and supplies
- http://www.shopatron.com/products/productdetail/part_number=PIN10010/164.0 the source for Pine Pro Graphite
- There are lots more but these are the ones I use based on seven years of testing and racing.