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Engineering Outreach to Cub Scouts with Hands-on Activities Pertaining to the Pinewood Derby Car Race*

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Since the Pinewood Derby (PWD) began more than fifty years ago, it has been one of a Cub Scout's first encounters with engineering principles. The PWD is an event in which seven- to eleven-year old Cub Scouts, with help from parents or leaders, construct a car out of a simple block of wood, four nails acting as axles, and four plastic wheels to race down a track under the power of gravity. Concepts such as friction, energy, roughness, and dynamics are indirectly learned as a result of a car's performance. To promote engineering education to elementary-level children, these concepts are taught to Scouts and their parents through the use of an outreach program, the organization, methods, and assessment of which will be discussed in this paper. Consisting of several stations to demonstrate the effects of rolling and sliding friction, wheel alignment, and weight distribution, the outreach program allows the Scouts to experience first hand how they can improve their car's performance. Hands-on activities as well as actual data also help keep the Scouts interested and motivated to build the most optimized car, and concurrently learn basic engineering principles. Since the PWD is held annually among hundreds of groups internationally, outreach programs have the potential of impacting thousands of Scouts every year and provide a basis for continued interest in engineering.

Keywords: outreach; Cub Scouts; tribology; Pinewood Derby; workshop

INTRODUCTION

SINCE the Pinewood Derby (PWD) began more than fifty years ago, it has been one of a Cub Scout's first encounters with engineering principles. The Pinewood Derby is an event in which seven- to eleven-year old Cub Scouts, with the help of adults, construct a car out of a simple block of wood, four nails acting as axles, and four plastic wheels to race down a track under the power of gravity. Due to the competitive nature of the race, the Scouts become highly motivated to build a faster car, which serves as an aid to teach the Scouts basic engineering principles with the use of an outreach program.

It has become increasingly important to engage young children in activities to expose them to engineering [1]. Technology is advancing rapidly; however, the skills necessary in the work environment must be taught through training programs at companies. Some of these basic skills can be learned earlier in secondary education, though, and outreach programs that include hands-on activities, such as the one outlined in this paper, prove to provide a stronger basis to build on in preparation for a person's career in engineering [2–3]. One key requirement is to excite the children and motivate them to increase their knowledge and pursue interests pertaining to engineering. Since the PWD is held annually with thousands of children and adults participating, outreach programs have the potential of impacting thousands of Scouts every year and provide a foundation for continued interest in engineering.

A lack of scientific data on the effects of PWD car performance variables as well as the opportunity to educate young Scouts, provided motivation to conduct several student projects in an introductory tribology course as well as a senior design project in the Department of Mechanical and Industrial Engineering at the University of Illinois at Urbana-Champaign (UIUC) from 2003 to 2005. From this research, a brochure (Appendix A) describing performance tips and basic concepts was created to give the Scouts during the outreach program; it was also distributed to local Scouts. Later, the obtained data will be added to the manual to provide Scouts and parents with experimental evidence to demonstrate the relative importance of certain design factors such as wheelbase, alignment, polishing, lubrication, and car mass.

Consisting of a presentation and several stations to demonstrate the effects of rolling and sliding friction, weight distribution, and wheel alignment, the program allows the Scouts to experience first hand how they can improve their car's performance. Hands-on activities in addition to experimental data also help keep the Scouts interested and motivated to build the most optimized car that they could construct. When the Scouts are finished

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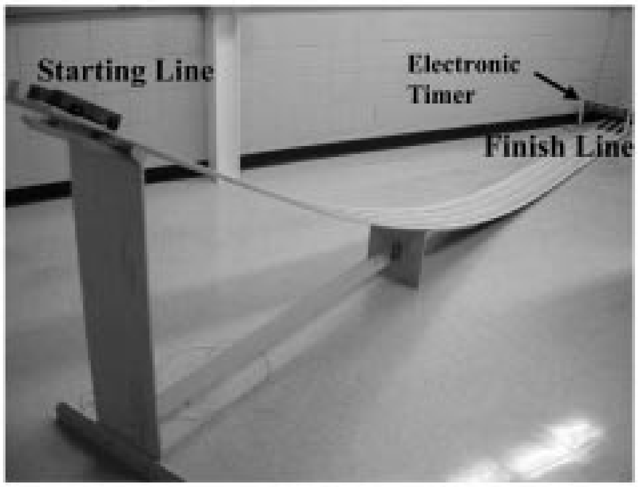

Fig. 1. Shortened version of a PWD track installed in the Tribology Instructional Laboratory at the University of Illinois at Urbana-Champaign (UIUC).

with the program, they not only leave with a competitive car, but also a better understanding of some basic engineering principles. To aid others in conducting similar outreach programs, a condensed version of this paper is provided as a step-by-step manual, which outlines the organization, in Appendix B. Furthermore, it is expected that not every parent or leader knows the scientific reasoning for the effects of each variable. Therefore, detailed explanations are provided that will help answer difficult questions posed by the Scouts.

PINEWOOD DERBY OVERVIEW

The PWD typically consists of a 4-foot tall, 32-foot long track with guide rails that gravity-powered cars must travel down. A shortened version of such a track was installed in the Tribology Instructional Laboratory at the University of Illinois at Urbana-Champaign (UIUC) and is depicted in Fig. 1. Although rules may vary between each Cub Scout pack, there are several that are common to all PWD races. First, the same Official Boy Scouts of America (BSA) PWD kit must be used. This ensures that everyone starts at the same level and must modify the parts themselves to improve performance. The contents of the kit are shown in Fig. 2. The assembled car consists of four axles (nails) that are inserted into wheels and pressed into the grooves on the bottom of a wooden block. Other rules are as follows: car weight shall not exceed 5 oz (142 g); wheel bearings, washers, and bushings are prohibited; only dry lubricant is permitted; the car shall not ride on any type of suspension; no starting devices are permitted; and loose materials are prohibited.

OUTREACH PROGRAM FORMAT

The outreach program is organized as a workshop in which concepts are explained to the Scouts through the use of simple experiments and actual PWD cars. The Scouts were organized in up to

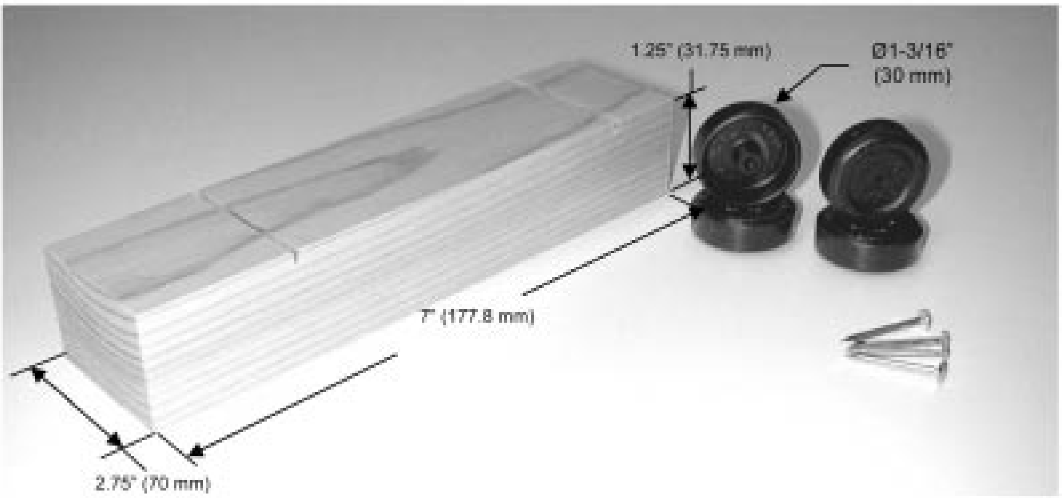

Fig. 2. Contents of an official Boy Scouts of America (BSA) Pinewood Derby kit: block of wood for car body, axles (nails), and wheels.

four groups of three to five Scouts each and rotated through four different stations consisting of:

Station 1—Sliding friction
Station 2—Rolling friction
Station 3—Alignment and aerodynamics and
Station 4—Weight distribution and energy.

These stations involve hands-on activities and modifying and assembling PWD cars, which the Scouts were able to test near the end of the program on the shortened track. The program is intended to be three hours in duration.

WORKSHOP DETAILS

Introduction to workshop

At the opening of the program, the objective of the workshop is explained to the participants. The objective is to learn techniques to modify a PWD car to improve its performance based on engineering principles and attempt to engage the Cub Scouts in the subjects through demonstrations and hands-on activities. It is also noted that there are several techniques to improve performance, but only those with the most significant effects are covered such as friction, wheel alignment, and weight distribution. Also, while car aesthetics help to keep the Scouts interested, there is no affect on the performance of the car. An interactive presentation is then shown to the Scouts containing videos of races where cars have undergone various modifications in the aforementioned categories.

In order to have a baseline of which to compare the Scouts' cars, a haphazardly assembled car was run down the track next to a higher performing car (built according to the guidelines presented in this paper), and the times were noted. It was explained that the car that had not been modified was much slower than the properly built car. The Scouts were then provided with an official BSA PWD car kit to work on during the workshop. At the end of the program, the Scouts were to compare their cars with the control car, allowing them to realize the effects of the engineering principles previously demonstrated. Throughout the program, safety was emphasized, and adults were instructed to assist Scouts with difficult and potentially hazardous tasks such as sawing or drilling.

Station 1: Sliding friction

This station focused on the importance of sliding friction in relation to the PWD car. When the Scouts first arrived at the station, they were given a chance to investigate three objects, shown in Fig. 3, prepared for sliding on a Formica inclined plane by touching and feeling the contacting surfaces and guessing which would be the fastest. The prepared objects were molded plastic with a wooden base. In order of smoothest to roughest, the bases had been covered with contact paper, 600-grit sandpaper, and a scouring pad, respectively. Care was taken to ensure that the objects have the same weight and nominal contact area. During the break-in period of a sliding interface, friction is greatly influenced by the roughness of the contacting surfaces. This is a result of the asperities of each surface elastically (recoverable) or plastically (non-recoverable) deforming, causing a force opposing the relative motion of the surfaces. Thus, objects with greater roughness will exhibit higher friction. It was then demonstrated that the different objects would travel at different rates according to their roughness as a result of sliding friction by releasing the objects on the inclined plane. The Scouts also had the opportunity to perform these tests themselves, increasing their interest and understanding of the friction phenomena involved.

It was then explained to the Scouts that this sliding friction would also affect the performance of their cars, as many Scouts know, friction in the PWD is their 'enemy' and should be eliminated. To minimize sliding friction, they were then shown and instructed how to polish the axles and sand the sides of the car body and wheels.

First, the axles (or nails) were addressed. A burr on the underside of the nail head, resulting from the manufacturing process, was shown to the Scouts. All axles from official PWD kits contain burrs, and if they are not removed, they can act

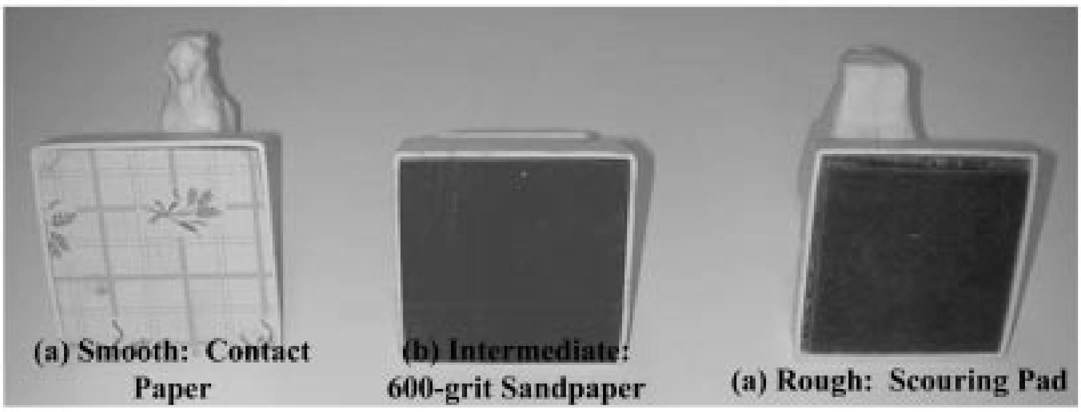

Fig. 3. Objects placed in order of increasing roughness: (a) contact paper, (b) 600-grit sandpaper, and (c) scouring pad.

like brakes, due to abrasive friction. After it was demonstrated how to remove the burr on the inside edge of the nail head using a small file, the Scouts had the opportunity to remove the burr on the remaining axles. It was emphasized that the Scouts needed to take care when filing the axles so as not to mar the nail shaft.

Next, the axles were to be polished to minimize sliding friction between the axle and the wheel hub. The portion of the nail that is important to be polished is the part where the wheel hub would be sliding against the nail. After removing the ridges, again a result of the manufacturing process, with 600-grit sandpaper, the Scouts polished the axles further using fine 0000 steel wool according to methods found in literature [4]. It was suggested that additional time and polishing steps may be necessary when the Scouts worked on their own cars at home as well as the addition of graphite between the wheels and the axles. Graphite, a solid lubricant commonly used in the PWD, at the atomic level forms sheets of atoms. Bonding of atoms within the sheets is much stronger than bonding between the sheets, resulting in particles that are easily sheared and provide superior lubrication [5]. Moreover, once the graphite is applied at the mating surfaces, it needs to be 'worked in' by rotating the wheel around its axle for several 10's of rotations. This allows the graphite to attach itself to the mating surfaces and promotes 'running in' of the metallic surfaces by removing large asperity peaks. This causes the surfaces to conform to each other with the majority of the relative movement residing in the graphite, greatly reducing friction.

It is important to note, however, that the axles should not be extremely smooth (mirror finish). For example, a perfectly smooth axle will not have the valleys necessary to hold graphite. This was confirmed with independent testing of unmodified, polished, and 'perfectly smooth' axles purchased from an Internet retailer. With three or less graphite applications, the 'perfect' axles performed better than the polished, but with further graphite applications, they performed similarly or worse [6]. This stresses the fact that graphite should be added often and worked in to obtain consistency. The axles that were unmodified performed worse, regardless of the amount of graphite application.

The last item that was addressed in this station was the sliding contact of the wheels against the car body. Using 600-grit sandpaper, the Scouts sanded the sides of the car, mainly near the axle slots until the car body was very smooth or silky. It was then necessary to make sure the inside edges of the wheel were smooth as well. The Scouts had the opportunity to feel the inside edges of the wheels, and it was explained that they would smooth the rough edge flashing at the rolling friction station.

Station 2: Rolling friction

The second station focused on the importance of rolling friction and gave large scale engineering examples where the effects of rolling fiction can be large, such as a rail wheels or a car tires. For this demonstration, three cylindrical objects of various roughness, and thus varying friction coefficients, were rolled down an inclined plane. Specifically, three PVC pipe sections with a 4.5-inch (11.43-cm) diameter were cut to about 3.5 inches (8.89 cm) in length. To create increased roughness, one pipe was scratched severely, while the other had small beads bonded to it. The three rolling objects are displayed in Fig. 4.

The Scouts were allowed to feel the cylinders and speculate which would be faster. The three pipe sections were then placed together at the top of the inclined plane and released at the same time. It was clearly indicated that the smoothest traveled fastest, while the others finish in the order of increasing roughness. This experiment was repeated by all Scouts until they recognized the effect of surface roughness on rolling friction. To demonstrate the effects of wheel eccentricity, the smooth cylindrical pipe was raced against a similar pipe that was not perfectly cylindrical to show that it would also be slower.

The importance of rolling friction with reference to a PWD car was then explained. The bumps on the contacting surfaces affect the friction between the pipe sections and inclined plane similarly to the sliding objects. Although the friction force parallel to the motion (sliding friction) may be close to zero, specimens with high roughness will exhibit more resistive forces in other directions due the interaction and deformation of larger asperities (in this case, beads and scratches). Unless the manufactured wheels are severely deformed or have

Fig. 4. Rolling demonstration objects: (a) smooth, (b) scratched, and (c) beaded.

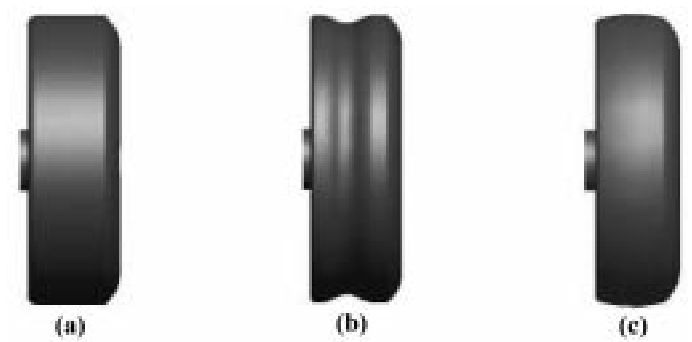

Fig. 5. Wheel profiles: (a) standard, (b) exaggerated deformed, and (c) curved.

rough surfaces, they should have only one burr resulting from injection molding that would affect rolling friction. Furthermore, if the wheel is eccentric, it will wobble causing contact with the body or guide rail, and it should be sanded until round.

One other important aspect of rolling friction is the area of contact between the wheel and the track. It was pointed out that the visible profile of the wheel could have many possible shapes (Fig. 5). For example, the cooling of the plastic wheel during production could result in a shape shown in Fig. 5(b). This shape, or even a flat profile, allows for a large area of the wheel to contact the track. A larger area of contact means that there will be more friction between the two due to an increased frequency of asperity interaction. Even though a curved wheel, such as the one shown in Fig. 5(c), is not usually allowed in competitions, it was explained that a wheel with such a curved profile will have a smaller area of contact, less rolling friction, and therefore, travel the fastest down the track.

For the hands-on activity, the Scouts sanded the edges of the wheels with 600-grit sandpaper, the significance of which was explained at the sliding friction station. Again, this task was performed at this station in an effort to distribute the activities between stations evenly and to focus on wheel modification on a single occasion. In addition to sanding the edges of the wheels, the Scouts also removed the small injection burr, resulting from manufacturing, with very fine sandpaper, again starting with 600 grit. The Scouts were also shown that the wheels could be sanded by placing them in a drill and wrapping sandpaper around it while rotating. However, due to safety concerns, this activity should be performed under adult supervision.

Station 3: Alignment and aerodynamics

This station focused on the importance of alignment of the PWD cars as well as the relative unimportance of aerodynamics. When the Scout group first arrived at the station, they were shown an aerodynamics demonstration. One derby car, using the original wood block, was raced down the track against another derby car with an aerodynamic wedge shape, both shown in Fig. 6. All other factors remained identical between the two cars, including their weight. After this demonstration, the Scout group and the instructor discussed briefly about how the aerodynamic shape, while it may look good, has no appreciable effect on PWD car performance as proven by the fact that cars exhibited a negligible difference in race times. This is to be expected since the speed and duration of a race are too small for aerodynamics to affect race times.

To demonstrate the importance of alignment, the Scout group was shown two strings resting on the table in the configuration depicted in Fig. 7. The group was then asked to determine if the wavy rope was longer than the straight rope and by how much. This demonstration was used to show that if a car is poorly aligned, it will travel a longer distance during a race as compared with a correctly aligned car. Alignment means that the car has been

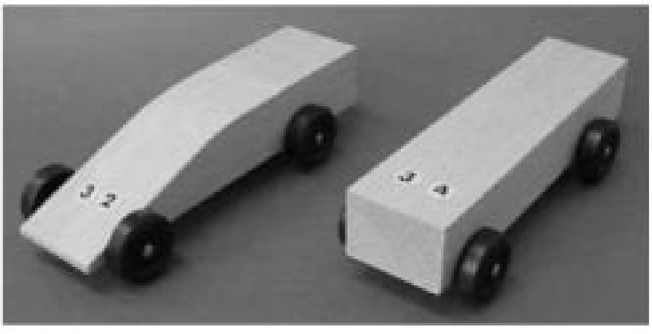

Fig. 6. PWD cars used for the aerodynamics demonstration.

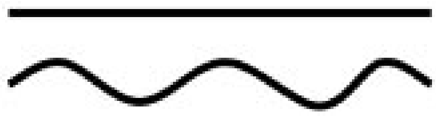

Fig. 7. String orientations for the alignment demonstration.

adjusted so that it will roll in a straight line. Furthermore, the instructor explained that since the PWD tracks have a center guide rail, the inside edge of the wheels would impact and rub on the rail and cause more sliding friction if the car did not travel in a straight line. That is, the effect of wheel misalignment is not only an increase in the distance that a PWD car has to travel, but also an increase in friction.

Finally, the group began the hands-on activity for this station. The instructor explained briefly how the alignment tool worked and checked the alignment of one of the unmodified cars. The PWD car body is placed up against the flat metal surface, and another metal piece is placed on top of the body against the metal surface to first check if the precut grooves were properly aligned, i.e., exactly 90° from the side of the PWD body. If not, then a line perpendicular to the side of the body was marked, and it was shown how to cut new grooves with a hand saw and mitre box. After checking alignment, it was demonstrated how to insert the axles into the grooves, and the Scouts were allowed to install their wheels and axles on the car. They were also given a spacing tool to check for the appropriate distance between the wheel and the body of the car, which was found to be optimum between 1/32 inch (0.79 mm) and 1/16 inch (1.59 mm). In this case, a standard CD inserted between the wheel and car body produces the correct gap.

During this activity, the instructor monitored how the Scouts inserted the axles in the car grooves to ensure that the axle angle did not deviate from 90°. After all the parts were assembled, the instructor checked the alignment and made any necessary re-adjustments while explaining the impact of those adjustments. To test the car, it was either run on the track or pushed on the hard floor to see if it traveled in a straight line. Further adjustments were made by lightly tapping the axle into the groove with a flathead screwdriver and mallet. Once alignment was ensured, a small amount of hot glue was applied to the axles to keep them in place.

Station 4: Weight distribution and energy

The final station of the program focused on mass (weight) placement and the relationship that mass has with energy. This was chosen to be the last station so that all other modifications on the car would be complete. It was then possible to increase the weight of the car to approach the limit of 5 oz (142 g) and obtain the most potential energy, which in turn will be converted to kinetic energy. The concepts of potential and kinetic energy were not differentiated, but rather energy as a whole as it relates to mass and height was described using two balls of an equivalent size as an analogy, as described next.

These concepts are somewhat intuitive, so they were simply clarified in the following ways. If two identical balls are dropped from different heights, the ball that is initially higher will have more energy because it has a larger distance for which to increase its speed before it hits the ground. To demonstrate this, two balls were dropped onto play dough with the initially higher ball producing a larger dent. Likewise, if two balls that have different weights, but are the same size, are dropped from the same height, the ball that is heavier has more energy because it will hit the ground harder. This is demonstrated similarly—the heavier ball making the larger dent.

Relating this analogy to the race, the more energy that a car has, the faster it will go when it reached the horizontal part of the track, since all the energy is then in the form of motion. Then, two cars of equal weight were raced on the track, one having its weight placed towards the front while the other had its weight towards the rear of the car. The car with the weight placed in the rear won by a small margin, a result of the back end of the car being higher than the front at the starting line. To make this idea clear to the Scouts, a schematic of a car on the track is shown and is given in Fig. 8. The effect of placing the mass towards the rear is an increase in height, *d*, and a corresponding increase in energy.

The process of placing the center of mass in the correct location may be somewhat difficult for the young Scouts, so adult help may be necessary. Although it was previously explained that the weight should be as far back as possible, it is thought that the weight should not be placed all the way at the rear as there is a risk of the front wheels lifting or easily hitting the guard rail. To clarify the importance of weight amount and

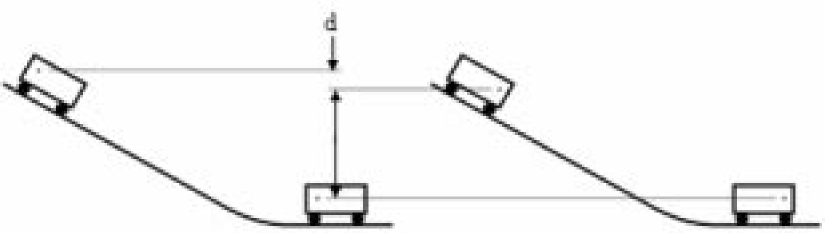

Fig. 8. Schematic showing the influence of mass placement, front-to-rear, on the amount of potential energy.

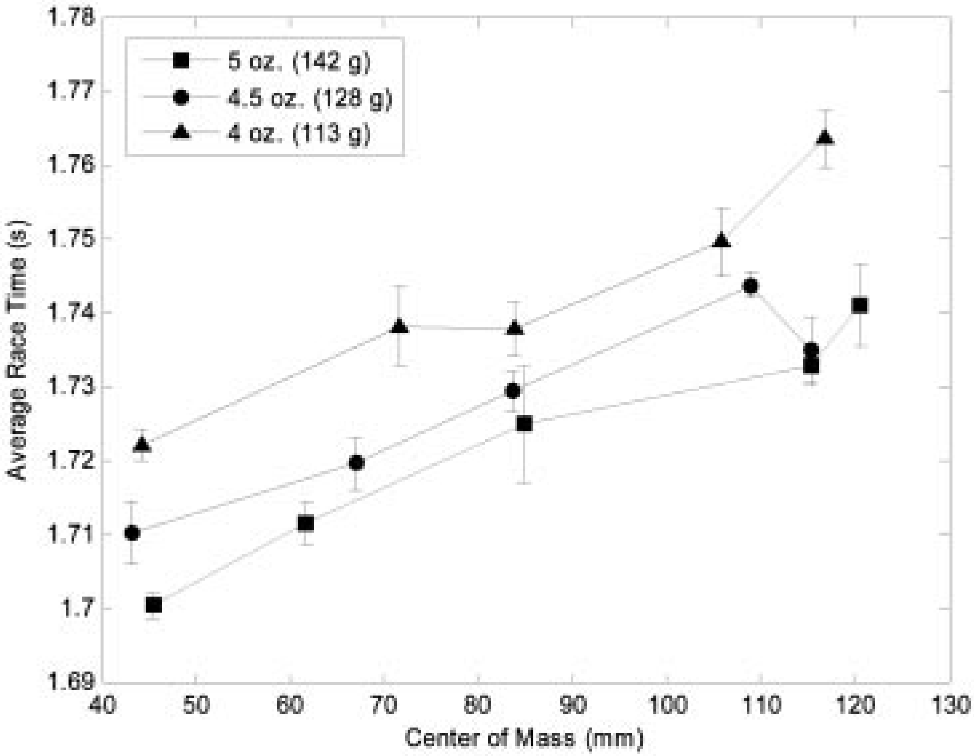

Fig. 9. This plot displays average race time versus the center of mass placement with varying mass. Center of mass placement is measured from the rear of the car.

placement, a chart is displayed with race times as a function of the center of mass and the amount of mass (see Fig. 9) enabling the Scouts to realize the relative impact of center of mass and total weight.

Conclusion to Program

Before the program was concluded, the Scouts reapplied graphite to their axles and had a chance to race their car against the original unmodified control car. The final race gave the group a fairly good indication of the amount of improvement that reduced friction, correct alignment and mass placement can provide. A car with all the modifications covered in the workshop was prepared and used to show improvement as well. It was emphasized that these races are often close and that even small improvements in time could mean the difference between winning and losing, as the older Cub Scouts very well know.

PROGRAM ASSESSMENT

After running the outreach program for two years, it was deemed a success as the majority of the Scouts understood why their car became faster with each modification and not just how to make them faster. To retain interest, an emphasis was placed on interactive demonstrations and hands-on activities—especially important for younger Scouts with shorter attention spans. The Scouts enjoyed the opportunity to test their cars after modifications were made to obtain instant gratification. Also, but maybe not a direct result of this program, the race times during the actual PWD were faster than previous years.

While generally not an issue in the programs that have been conducted, it is important that each Scout is accompanied by a parent or adult to increase supervision and interaction. However, the Scouts should be encouraged to do as much of the work as possible to increase their understanding and interest. A recommendation for future PWD outreach programs is to distribute the *Tips for Improving the Performance of Your Pinewood Derby Car* and *Pinewood Derby Workshop Manual* brochures to parents prior to the workshop, so they have an idea of the workshop organization as well as the justifications for modifications.

SUMMARY

A Cub Scout PWD outreach program has been developed and used to teach elementary level Scouts basic engineering concepts. The program comprised four stations: Station 1—Sliding friction, Station 2—Rolling friction, Station 3—Alignment and aerodynamics, and Station 4—Weight distribution and energy. The program uses both demonstrations and hands-on activities and is intended to be three hours in duration. It became a useful tool for introducing Cub Scouts to engineering and allowed them to apply what they have learned immediately to improve their cars to gain a better understanding. Response from the Scouts and parents has been very enthusiastic, confirming the value of its addition to the Cub Scout program. To aid others in conducting similar outreach programs involving the PWD race, a step-by-step manual for the workshop is provided in Appendix B. The basic concepts and tips for improving PWD car performance are also summarized in a brochure that was distributed to the Scouts and is also included as Appendix A. Owing to the amount of PWD competitions held worldwide, there is an opportunity to increase engineering interest in thousands of young boys every year.

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REFERENCES

1. J. Douglas, E. Iversen, and C. Kalyandurg, Engineering in the K-12 classroom: An analysis of current practices & guidelines for the future, Production of the ASEE Engineering K12 Center (November 2004).
2. M. D. Symans, Introducing middle school students to engineering principles using educational bridge design software, *Int. J. Eng. Educ.*, **89,** 2000.
3. R. Speaks, Hands-on engineering for high school students, *Proceedings of the 1998 Annual ASEE Conference,* Seattle, WA, (June 1998).
4. J. Gargiulo and S. Gargiulo, Winning pinewood derby secrets, Trumbull, CT, (2001), accessed at www.pinewoodpro.com (September 2005).
5. J. A. Williams, *Engineering Tribology*, p. 368. Oxford, UK (1996).
6. J. Ballou, S. Camis, S. Koo and K. Wait, MIE470 Team 13: The ultimate pinewood derby car, University of Illinois at Urbana-Champaign, (13 May 2005).

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Andreas A. Polycarpou is an Associate Professor and Kritzer Faculty Scholar at the Department of Mechanical and Industrial Engineering at the University of Illinois Urbana-Champaign. He received his Ph.D. in Mechanical Engineering from the University at Buffalo, NY in 1994. Before joining the University of Illinois in 1999, he was a visiting lecturer at the University of Buffalo from 1994-1995, a post-doctoral fellow at the Technion-Israel Institute of Technology from 1995-1997, and from 1997-1999 he was a staff scientist at Seagate Technology. Polycarpou's research interests are micro/nanotribology, microtribodynamics, surface characterization and dynamics of magnetic storage devices and conventional engineering surfaces. Polycarpou is the author of over 50 archival journal papers, 3 book chapters, the editor of 5 volume proceedings, and holds 11 United States patents. He is the recipient of several awards including the NSF CAREER award, the 2001 ASME Burt L. Newkirk Award, and the 2005 Xerox Research Award. He is also the 2005-2006 Chair of the ASME Tribology Division, a member of ASME's Basic Engineering Operating Board and a member of ASME's Thurston Lecture Committee. He is also an active Scout leader with Pack 119 and Troop 101 of Champaign, Illinois.

Appendix A: Tips for Improving the Performance of Your Pinewood Derby Car

Tips for Improving the Performance of Your Pinewood Derby Car

Microtribodynamics and Tribology Laboratory
University of Illinois at Urbana-Champaign

The following Engineering students at the University of Illinois contributed to the preparation of this Guide:

Michelle Cannaday
Jessica Crompton
Tim Solzak
Mike Zhang

Under the supervision of:
Andreas A. Polycarpou

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Appendix A: Tips for Improving the Performance of Your Pinewood Derby Car

Tips for Improving Your Pinewood Derby Car

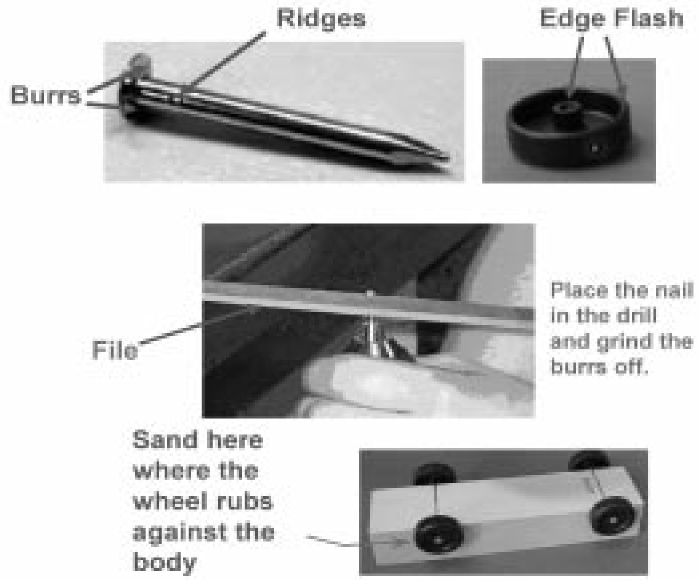
- First and most importantly, be safe.
- Do not use any tools that you have never used before. Have an adult show you how to use the tool. Always work under adult supervision.
- The following tips will help you improve the performance of your car.
- In general there are at least 3 areas that significantly contribute to a high-speed car: (a) reducing sliding and rolling friction by using a lubricant and by smoothening the contact parts; (b) ensuring that the finished car is traveling on a straight line and not hitting the center rail; and (c) weight of the car to be 5 Oz and not less.

Lubrication

- You want to decrease the friction which can act as a brake and will slow down your car.
- Use a solid lubricant, such as graphite, to decrease friction. Do not use oil, as it is not allowed.
- There is friction everywhere there are moving parts that are touching, so be sure to put graphite in all of these places. These include: everywhere on the axles, the axle hole in the wheel and on the car where the wheel may touch the car.
- Spin the wheels many times (preferably in the car-forward direction) so that the graphite can work its way into them. This is referred to as the break-in process. Simply adding graphite, without spinning, may not do the job.
- Remember to add graphite right before check-in, and again spin the wheels to break them in.

Reducing Sliding Friction

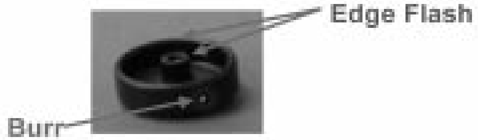
- Sand the side of the wooden car block with 600 grit sandpaper. Then move to a finer grit, if available.
- Remove the burrs from under the nail heads with a small file by using a drill, as shown below, or by hand. Remove the ridges on the axle shaft with 600 grit sandpaper. Then polish the shaft with steel wool. Remember to ask an adult if you are going to use a drill.
- Sand off the edge-flashing of the wheel and wheel hub. Since the wheels are plastic, be careful not to sand too much and warp the wheels. Use 600 grit sandpaper, then move to a finer grit.

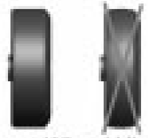


Appendix A: Tips for Improving the Performance of Your Pinewood Derby Car

Reducing Rolling Friction

- Remove the injection burr from the wheel's surface. Use 600 grit sandpaper then move to a finer grit. Since the wheels are plastic, be careful not to sand too much and warp the wheels. *Also, note that the rules may not allow for wheel rounding* (which by the way helps the car go faster).

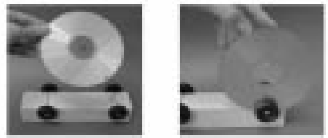



Front Wheel View

Correcting Alignment

- *Make sure the original axle grooves on the derby car are* straight by lining them up with something that forms a right angle, e.g. a T-square. *Ask your parents to help you* with this. If necessary, you can make new axle grooves.
- Take good care when inserting the axles. If the axles are inserted crooked, it will be difficult to adjust alignment later.
- Use something that is about 1/16" - 1/32" to make sure all the wheels have the same spacing from the body. *A simple* computer CD can be used, as it is closed to 1/16" thick. Ask for an adult to help when working with sharp objects.

- Gently push the assembled car on a flat surface to find out if the car rolls straight. An actual race track is best for testing if it is available.
- If the car does not roll straight, try adjusting the axles on the car.
- *Once* the axles are completed use some glue to secure then on the car body (away from the wheels).



Weight

- Try making your car to be as close to the 5 oz. limit.
- The round weights shown below work well, but BB's, nuts, or bolts work as well, as long as they are glued to the car.
- It is best to try and evenly distribute the weight, with the majority of the weight toward the rear


Weights in the rear of the car

Appendix A: Tips for Improving the Performance of Your Pinewood Derby Car

Notes:

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DEPARTMENT OF MECHANICAL & INDUSTRIAL ENGINEERING

Appendix B: Pinewood Derby Workshop Manual

Pinewood Derby Workshop Manual

Microtribodynamics and Tribology Laboratory
University of Illinois at Urbana-Champaign

The following Engineering students at the University of Illinois contributed to the preparation of this Guide:

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B1

Opening Activity
(approx. 10 mins)

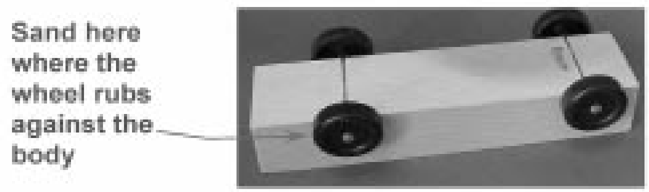
- Welcome the scout group to the workshop and introduce each presenter.
- First, gather the scout group around the race track and place the unmodified control car(00) and the completed car(99) on the track.
  - Explain to the scouts that one car is simply assembled "out of the box" while the other has been optimized.
- After the demonstration, tell them that although there are many different modifications one can do, only the most important will be taught here: decreasing sliding and rolling friction, and improving alignment and weight distribution. A presentation may also be shown containing videos of unmodified cars racing against cars modified in the aforementioned categories.
- If the scout group is sufficiently small, then skip this step. Divide the scout group into ~4 groups of 3-5 scouts, and direct each group to a station. They will be rotated around to each station throughout the workshop.
- If a scout does not have a car they are already working on, provide them with a new kit. They will take their cars from station to station and race them later to demonstrate what kind of improvements can be achieved. Be sure to tell them not to assemble the car until right before the race. This will cut down on disassembly time at each station.
- Be sure to explain the terminology used throughout the workshop, such as alignment, sliding friction, etc.

Sliding Friction Station
(approx. 25-30 mins)

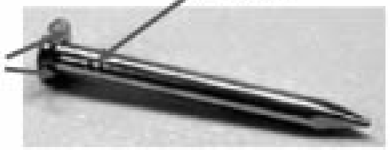
1. Show the sliding friction demonstration when the scout group first arrives at the station.

- Have the scouts gather around the taller of the two sliding boards.
  - Pass around the three prepared sliding objects and explain that they all have different roughness.
  - Have the scouts guess which object will slide the fastest.
  - Next, demonstrate that the different objects will slide at different speeds according to their roughness.
- Explain to the scouts that roughness increases sliding friction and will affect the performance of their Pinewood Derby cars. To minimize sliding friction, we need to sand the sides of the car body and polish the axles.

2. Get one scout started with sanding the sides of the car, mainly near the axle slots, with 600 grit sandpaper. The car body should feel very smooth, silky.



- Demonstrate how to remove the burr on the inside edge of the nail head.
  - Using a small file gently scrape the nail head back and forth on the file, taking care not to mar the nail shaft.



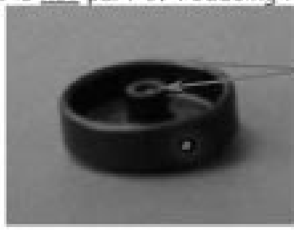
- Explain that if this burr is not removed, it will act like a brake, slowing down the car.
- Have the scouts remove the burr on the remaining nails/axles.

3. Next, have the scouts polish the axles by first using 600 grit sand paper. One method of sanding is to fold the paper into a ½ inch strip, fold the strip around the nail, and while holding the paper tightly, spin the nail.

- Explain that the portion of the nail that is important is the half nearest to the nail head, since this portion will be sliding in the wheel hub.
  - After removing the ridges with the 600 grit sandpaper, polish further using fine 0000 steel wool.
- Explain that with longer sanding time, the axles can become highly polished. Metal polish can also be used after sanding. Adding graphite or other dry lubricants will decrease friction further and should be worked into the axles by spinning the wheels many times.

5. Finally, explain that the wheels may slide against the car body, which is why the car body was sanded. Now we need to make sure the edge flash on the wheels are also smooth.

- Have the scouts feel the inside edges of the wheels.
- Explain that they will need to smooth the rough edges at the next station so that all wheel modifications can be done at once to save time. *Make sure the scout group is not confused about this.* Smoothing out the sides of the wheels is <u>not</u> part of reducing rolling friction.

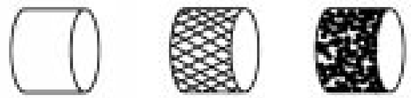


Rolling Friction Station
(approx. 15-25 mins)

1. Show the rolling demonstration when the scout group first arrives at the station

- Use the three PVC tubes (smooth, scratched, beaded) on the inclined plane
  - Have the group inspect the tubes, and guess which will roll the fastest.
  - Roll simultaneously. Smooth should be fastest, followed by scratched and finally beaded.

- Repeat demo until all scouts observe the differences.



- Explain that the bumps on the surfaces affect the friction between the roller and inclined plane.
  - Note that the effects of rolling friction are much less than that of sliding, which is why the demonstration needed closer observation.
  - Allow a couple minutes for questions.

2. Next, explain how rolling friction influences the Pinewood Derby cars. Unless the wheels are severely damaged or warped, they should only have one injection burr that will increase the friction between the wheel and track.

- Point out the small spot on the wheel. If asked, explain how the burr is created (the place where melted plastic is injected into a mold the shape of a wheel).

3. Explain one additional aspect of rolling friction—the area of contact between the wheel and the track.

- Point out the profile of the wheel, which could have many different shapes.
  - Explain that a flat shape or any other shape that has a larger area in contact with the track will cause more friction.
  - Finally, explain that if the competition allows it, the wheels should be sanded into a curved shape that decreases the area that actually touches the track. Refer to the figure below.
  - Allow a couple minutes for questions.

4. Finally, begin the hands-on activity.

- The first task is performed in an effort to evenly distribute the activities between stations and to focus on the wheels on a single station. Make sure the scout group is not confused about this. Smoothing out the sides of the wheels is still part of reducing sliding friction.
- These activities should be performed with very fine sandpaper, starting with 600 grit.

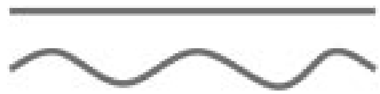
    - The first activity—sanding the inside edges of the wheels—was explained at the sliding friction station.
    - In addition to sanding the edges of the wheels, the scouts will remove the injection burr discussed at this station.
- Allow several minutes to answer any questions.

Alignment/Aerodynamics Station

(approx. 15-25 mins)

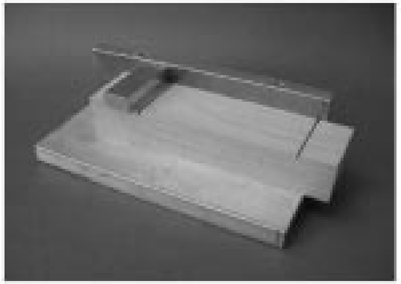
1. Show the aerodynamics demonstration when the scout group first arrives at the station.
- Use the pair of aerodynamics test cars - one wedge shaped and one original block.
    - Race the cars on the track.
    - Be sure to mention that both cars are otherwise identical, including weight.
- Sit the group down around the station and discuss how the wedge shaped car does not run faster than the original block. This shows that aerodynamics has a very insignificant effect on a car's performance.
- Leave about 1 minute for questions.

2. Next, show the pair of strings to the scout group. The strings should be arranged on the table prior to the beginning of the workshop.



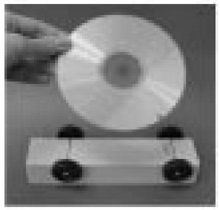
- Ask the group which rope is longer and by how much.
    - Discuss with the group that a misaligned car will travel down the track like the wavy rope while a straight car will travel a much shorter distance.
    - Also mention that since the Pinewood Derby tracks have a center guide rail, the inside edge of the wheels will rub on the rail and cause much more sliding friction if the car does not travel in a straight line.
    - Allow a few minutes for questions regarding the alignment.

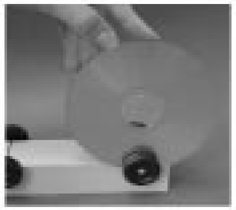
3. Begin the hands-on activity of aligning and installing the axles (be sure to allow the scout group to do as much of each exercise as possible).
- Briefly explain how the alignment tool works: butt the car body against the short wall of the alignment tool with the axle grooves facing up. Place the small rectangular metal piece on the car body and check if the grooves are straight.



- Show the group how to mark lines for new grooves if the original ones are not perpendicular to the edge.
- The car provided to the scout group will have straight axle grooves so it won't be necessary to make new grooves.

• Explain how to insert the axles and allow the scout group to install their wheels and axles on the car.
  - Provide them the spacing tool to check for the appropriate distance between the wheel and the body of the car: 1/16" - 1/32".





- During this activity, the instructor needs to monitor how the scouts insert the axles to ensure that the axles are not inserted too crookedly. It may be difficult to fix later.

4. Finally, double check all the parts on the car and make sure they are installed correctly.
   - Double check the alignment by gently rolling the car on a level floor or on the track. Make any necessary re-adjustments by lightly tapping the axle in the groove with a flathead screwdriver.

Allow several minutes for questions regarding the topics discussed at this station.

Weight Distrubtion/Energy
(approx. 15-20 mins)

1. Show the energy demonstration when the scout group first arrives at the station.

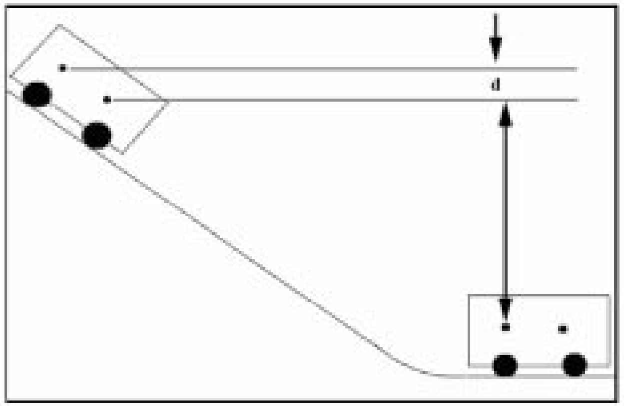
• Show the scouts that two balls of different weights have different energies.
  - Drop the balls from the same height onto play dough.
  - Explain that the heavier ball had more energy resulting in a larger dent.

• Show the scouts that two balls of equal weight at different heights have different energies.
  - Drop the balls from different heights onto play dough.
  - Explain that the ball initially held higher had more energy resulting in a larger dent.

• Let the scouts try dropping the balls and answer any questions.

2. Explain how the energy principle applies to the PWD cars.

- Race two cars of equal weight, but one with weights mounted at the rear and one with weights mounted at the front.
  - Explain that the car with the weight at the rear has more weight higher as a result of the car being on an incline.
  - Instruct the scouts and parents to mount the weights just in front of the rear axle to obtain the most energy while maintaining stability of the front axle.



Closing Activity
(approx. 10 mins)

- At this time, have all the scouts come to the alignment station and make a final check of the cars' alignment.
- Apply a small amount of hot glue to the axles to keep them in place.
- Have each scout race their improved cars against the unmodified car on the track.
- The final race should give the scout group a fairly good indication of the amount of improvement reduced friction and correct alignment can provide.
- Give the scout group one more chances to ask any questions regarding the workshop and PWD in general.

Appendix B: Pinewood Derby Workshop Manual

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