Physics Lecture 3 - Experiments with Hodges' Nickel Plated Axles

Summary/Conclusions

Rigorous experimental physics procedures have been applied in the Jobe Consulting Laboratory to analyze friction reduction benefits of nickel plated axles available from Hodges Hobby House (Winderby.com). Using the Simple But Fast (SBF) pinewood derby car, standard Scout Shop kit axles (kit 30176-17007) lubed using the Speed Package (with Super Z graphite) showed a coefficient of wheel/axle friction (MU) of 0.108. Hodges nickel plated axles treated with exactly the same lube procedure showed a MU of 0.065, a substantial reduction. Using the mathematical modeling program Virtual Race, this reduction in coefficient of friction means the car with the nickel plated axles will finish 1/2 car lengths ahead of the standard axle car on a standard 16 ft horizonal run inclined plane track. On a track with a long 36 ft horizontal run such as the one used in the National Race in Irving, TX, in 2005, the finish difference is a full car length ahead using Hodges' axles.

Background

In the Physics of the Pinewood Derby book, MU tests are described which use an old nickel plated Hodges' axle circa 1996. In those experiments, there was no substantial difference noted in tests comparing those axles with standard kit axles. These new Hodge's axles, reflecting an ownership change and new axle preparation procedures, look and perform quite differently from the old axles. **Figure 1** shows 4 axles. One is a standard Scout Shop kit axles (kit 30176-17007) fresh from the box. Another is a fresh Hodge's axle which has the end ground to a point so it will fit in the same hole as the standard axle. A third axle is a standard axle after graphiting and the fourth axle is a Hodge's graphited axle. The individual axles are not identified in the photo to illustrate how similar they look.

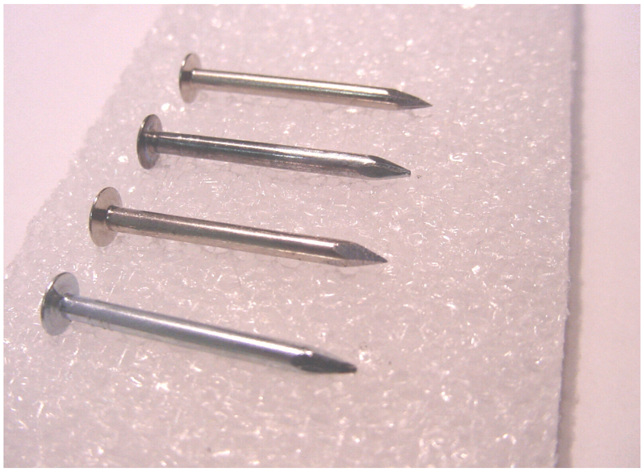

Figure 1. *Four axles: A fresh and graphited nickel plated axle and a fresh and graphited zinc plated axle.*

Experimental Apparatus - Description

A special friction test ramp (FTR) was constructed and the starting gate is shown in **Figure 2**. For those of you who have the Virtual Race (VR) CD, a simple manual version of this track is shown under Help/Advanced & Cub car testing/Advanced MU testing. The starting gate has low moment of inertia needles in the brass cross tube that hold the cars in place until the trigger is pulled. At that time, a microswitch is closed that sends a start signal to a Newbold DT8000 computer compatable digital timer. The DT8000 displays elapsed time on its screen but also communicates with a PC over a serial COM port which can be read in real time by the Windows Hyperterminal program. This program is a standard Windows accessory program.

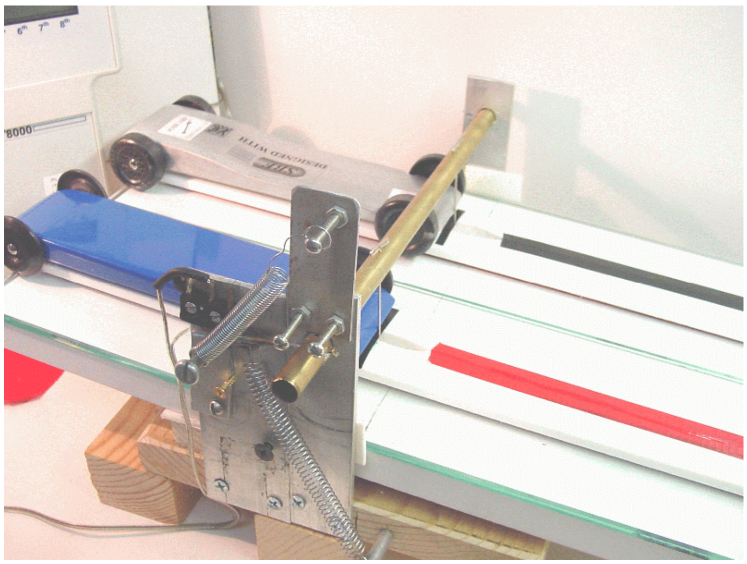

Figure 2. *Showing the* Blue Streak *car and the* SBF *car in the starting gate of the* friction test ramp (FTR).

Figure 3 shows the full length of the FTR. A lamp placed over the finish line activates the DT8000 for 2 ramps and the shadow of a car crossing the finish line stops the timer for that ramp.

The ramp has a smooth glass surface to ensure no rolling friction. The center strip is teflon® or a similar low friction polymer. The air speed at the finish line is approx. 90 cm/s or 2 mph. Normal race track finish speeds are about 484 cm/s or 11 mph. At 2 mph the Virtual Race program shows that air resistance is only 1/100 of frictional drag for MU = 0.10, a common value. The speed retardation measured by the FTR is thus essentially 99% caused by wheel/axle friction.

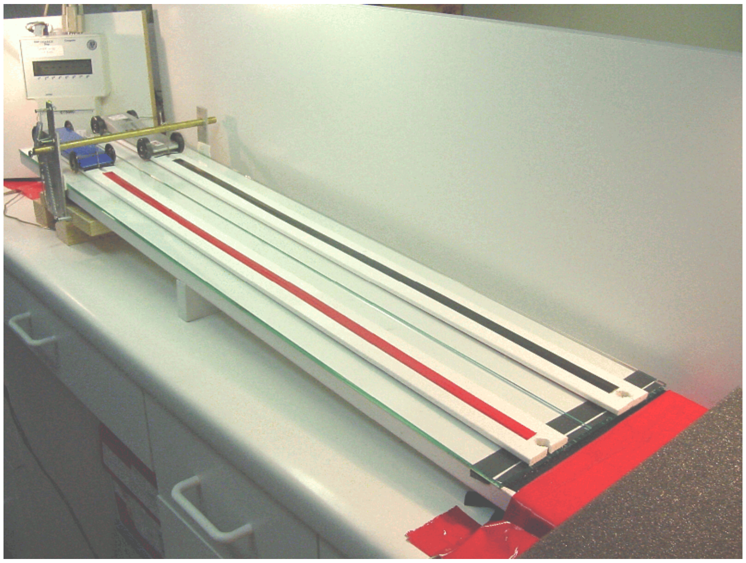

Figure 3. *Showing the full length of the* FTR.

Experimental Data

Table 1 shows ramp times for the Blue Streak and SBF cars. The Blue Streak, loaned to the author by a friend, was used as a control car. This car was known to possess a low coefficient of friction and had won many races in the Sam Houston Council during the 1990s. The axles appeared to be standard kit axles but the wheels, turned down for low moment of inertia, were the old pre 1991 standard wheels. The cars were run several times and then lanes were switched between lane A (red) and lane B (black). The overall average (OAVG) in **Table 1** shows that the Blue Streak car has close to the same MU value as does the Hodges nickel axles on the SBF, being 0.057 and 0.061 respectively. The MU value is derived from the time by running the Virtual Race model as shown in the next section. **Table 2** shows what happens when kit axles are used on the SBF with the same wheels and identical lube procedures.

Table 1-Axle comparison using Super Z graphite

BLUE STREAK			SBF		
? Axles + Super Z			Nickel Axles+Super Z		
Ramp	Time	MU	Ramp	Time	MU
B	1.6960		A	1.6976	
B	1.6994		A	1.6819	
B	1.6789		A	1.6692	
B	1.6666		A	1.6722	
B	1.6620		A	1.6775	
B	1.6550		A	1.6773	
AVG	**1.6763**	0.057		**1.6793**	0.064
STD	**0.0167**			**0.0091**	
A	1.6824		B	1.6694	
A	1.6911		B	1.6747	
A	1.6550		B	1.6913	
A	1.6767		B	1.6602	
A	1.6600		B	1.6669	
A	1.6959		B	1.6765	
AVG	**1.6768**	0.057		**1.6732**	0.058
STD	**0.0150**			**0.0097**	
OAVG	**1.6766**	**0.057**		**1.6762**	**0.061**

Table 2-Axle comparison using Super Z graphite

BLUE STREAK			SBF		
? Axles + Super Z			Std Kit Axles+Super Z		
Ramp	Time	MU	Ramp	Time	MU
B	1.6862		A	1.7411	
B	1.6572		A	1.7497	
B	1.7018		A	1.7374	
B	1.7048		A	1.7396	
B	1.7119		A	1.7437	
B	1.6664		A	1.7123	
B	1.6305		A	1.7074	
B	1.6474		A	1.7184	
B	1.6747		A	1.7388	
AVG	**1.6757**	0.056		**1.7320**	0.113
STD	**0.0263**			**0.0143**	
A	1.6910		B	1.7380	
A	1.6896		B	1.7331	
A	1.6789		B	1.7167	
A	1.6772		B	1.7219	
A	1.6687		B	1.7113	
A	1.6721		B	1.7023	
A	1.6665		B	1.7364	
A	1.6797		B	1.7233	
A	1.6712		B	1.7060	
AVG	**1.6772**	0.058		**1.7210**	0.103
STD	**0.0082**			**0.0123**	
OAVG	**1.6764**	**0.057**		**1.7265**	**0.108**

The MU value increases substantially from 0.061 to 0.108. In **Table 3** is shown data from timing tests where new nickel plated axles are again used to exactly duplicate the conditions behind **Table 1** data. The results are close, showing a MU of 0.069. Notice the control car Blue Streak uniformly gave 0.057, 0.057, and 0.059 for its 3 runs in **Tables 1**,**2**,and **3**. Using the average of SBF MU results, we have for a MU difference 0.108 - 0.065 = 0.043, a very substantial MU improvement. The STD stands for standard deviation which is a measure of how repeatable the times are. Converting the STD to equivalent MU values we find the MU repeatability to be ±0.0005

Table 3-Axle comparison using Super Z graphite					
BLUE STREAK			SBF		
? Axles + Super Z			Nickel Axles+Super Z		
Ramp	Time	MU	Ramp	Time	MU
B	1.6664		A	1.6896	
B	1.6678		A	1.6825	
B	1.6679		A	1.6849	
B	1.6811		A	1.6877	
B	1.6680		A	1.6962	
B	1.6727		A	1.6892	
AVG	**1.6707**	0.052		**1.6884**	0.073
STD	**0.0051**			**0.0043**	
A	1.6694		B	1.6770	
A	1.6828		B	1.6856	
A	1.6763		B	1.6780	
A	1.6913		B	1.6881	
A	1.7019		B	1.6879	
A	1.6966		B	1.6657	
AVG	**1.6864**	0.066		**1.6804**	0.065
STD	**0.0113**			**0.0079**	
OAVG	**1.6785**	**0.059**		**1.6844**	**0.069**

Conversion of Time to Coefficient of Friction

The Virtual Race program provides finish times and velocities for different gravity driven cars run on various tracks. Only 3 track specifications are needed (in addition to air density and gravitational constant) but for the car 12 parameters are needed. Below in **Table 4** we have the FTR specs, a standard inclined plane (32 ft overall) track specs, and parameters for the Blue Streak and SBF car. The steps are as follows:

1) Enter the FTR and SBF parameters into the VR program. For the FTR horizontal run distance we need to enter the CM distance for the car to trick the program into thinking SH = 0.
Click on the Vary Car Parameter Tab, select MU, hit [run] and you will get an output screen with a table of MU vs time (Similar to this screen done in another application). Look on the table close to the value **1.6844** and you will see MU = **0.069** (see **Table 3**).

2) Enter the Blue Streak car parameters and repeat the above procedure to see that **1.6785** gives a MU = **0.059** result (see **Table 3**).

3) Change the track to a Standard Track of the inclined plane type with parameters as in **Table 4.** Then run the SBF car at the 2 values of MU = 0.108 (Zinc axle) and 0.065 (Nickel axle) and you will get a screen similar to this1 that shows the latter car has a 0.509 car length advantage at the finish line.

Table 4 - Inclined plane track and car parameters			
Track Parameters (rho = 0.001225,g = 979.27)	FTR	Standard	Units.
Length of horizontal run (SH)	4.909/4.240	396.24	cm
Start height of ramp above horizontal (H)	4.608	119.382	cm
Projected length of ramp on horizontal (D)	73.660	456.419	cm
Car Parameters	Blue Stk	SBF	Units.
Number wheels touching (NK)	3	3	
Moment of inertia of body (IC)	2000	2000	g cm^2
Moment of inertia of wheel (I)	2.466	1.558	g cm^2
Projected area of a wheel (AW)	2.910	1.811	cm^2
Projected area of body (AB)	7.430	5.108	cm^2
Drag coefficient of wheel (CW)	0.500	0.500	
Drag coefficient of body (CB)	0.420	0.280	
Mass (weight) of body plus wheels (M)	141.750	140.400	g
Radius of a wheel (RW)	1.515	1.492	cm
Radius of an axle (RA)	0.113	0.118	cm
Coefficient of friction (MU)	0.070*	0.070*	
Center of mass re body center (CM)	4.240	4.909	cm
* Nominal friction values around which to vary MU on the FTR test track.			

Discussion of Results

The large improvement in MU for Super Z graphite on a nickel surface compared to zinc should hold for other high purity graphites as well. Evidently the smoothness of the nickel, if polished properly, helps lay down a uniform monomolecular graphite film. Because smoothness correlates with hardness, one might predict that chromium axles might show a further improvement. The Vickers hardness numbers are: zinc = 90-130, nickel = 250-350, chromium = 700-1000. Experiments on chromium plated axles are planned next.