

Physics Lecture 9 - The Effects of Air Drag on PWD Race Times

Figure 1 - Showing 8 cars built according to the aerodynamic summary of bodies and wheels in Lecture 8.

Summary/Conclusions

The virtual race (VR) program is used to demonstrate the performance of the car bodies and wheels shown in <u>Lecture 8</u>. The 4 bodies are run with the Standard Cub wheels and the RS Racing wheels. The slowest combination is about 2 car lengths behind the winner at the finish line. When the RS wheels have their moment of inertia increased to that of the Standard wide wheels, the air effect alone is shown to cause about a 0.7 car length spread.

Virtual Racing of the 8 Cars from Lecture 8

It takes just a few minutes to build 8 virtual cars that have the parameters of **Figure 1.** See <u>Lecture 10</u> for a more thorough description of parameters other than the 5 in **Figure 1. Figure 2** shows the VR car edit/create screen with parameters of the top car in **Figure 1**, which is called CAR_1B1W. We keep the car mass (weight), wheel and axle radius, coefficient of friction, CM position, and number of wheels touching constant for all 8 virtual cars.

We start with the StdTrk_HOUSTON_C-BT track. The HOUSTON means is uses the local Houston *g* force and air density. The "C" means this track has a circular are ramp (16' - 7") and a horizontal run (16' - 3'). The net drop height = 47". The BT means the timer is set to trip on the front bumper and not the car CM. Select Race Group of Cars tab and you will see on the left all the cars in your main car file. Put a check next to the 8 cars we just built as the ones selected to race. Now we race by clicking on [Go].

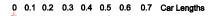
of bodies and wheels in Lecture 8.							
Car Parameters		? ×					
Carname: CAR_1B1W							
Switch from cgs	s to mks (SI): 🛛 🛛	-					
Nbr wheels touching track (NK): 3	-						
Moment of inertia of body (IC)	2000	gram cm^2					
Moment of inertia of a wheel (1)	5.123	gram cm^2					
Projected area of a wheel (AW)	2.960	cm^2					
Projected area of body (AB)	7.430	cm^2					
Drag coefficient of wheel (CW)	0.50						
Drag coefficient of body (CB)	0.84						
Mass (weight) of body plus wheels (M)	141.75	gram					
Radius of a wheel (RW)	1.515	cm					
Radius of an axle (RA)	0.113	cm					
Coefficient of friction (MU)	0.10						
Center of mass re body center (CM)	0	cm					
Non-Pinewood Derby Car							
Length of car (L)	17.78	cm					
Mass (weight) of wheel (MW)	3.5867138	gram					
X Cancel	Save						
		·					

Figure 2 - Showing the VR car create/edit screen. Note only 3 wheels touch and considered rolling.

Discussion of Results

The results of the 8 car race on the Standard "32" ft track with a circular arc ramp is shown in Figure 3. Consider the top 4 finishers of the 4 cars using the RS wheels (see Hodges wheels). It shows that body projected area size and body drag coefficient can cause a difference of up to 0.374 car lengths difference at the finish line. The last 4 finishers running the wide Cub standard wheels with a much larger moment of inertia show precisely the same finish differences caused by air effects on the body. But there is a big slowdown of about 1.5 car lengths caused by a combination of much larger moment of inertia and much larger wheel projected area. On the inclined plane ramp (same overall projected shadow on the floor as the circular arc) one can see that the air effect is about 15% smaller, i.e., 0.328 vs. 0.374. This is because the circular arc ramp allows the maximum velocity to be approached somewhat faster than on the inclined plane.

To get rid of the wheel moment of inertia effect, play like the RS speed wheels are made from lead so they have a large moment of inertia of 5.123 g-cm² like the Cub wide wheels. So build 4 virtual cars to replace the Delrin® RS wheels with ones of the same area, coefficient of friction, etc. and name the cars the same except put a "L" in the name for "lead wheel". Figure 5 and Figure 6 show the results. The purely air effect shows a spread of almost 0.7 car lengths on the circular arc track data of Figure 5. Fig. 7 gives a picture of the finish line for this race. Although this is a theoretically perfect race, it shows that air effects are indeed substantial and are a significant factor even in real nonperfect racing after random effects (center strip bumping, etc) are Figure 4 - Race results for the standard inclined plane ramped track. averaged out. Incidentally, by looking at the time differences between, say, 4B2W and 4B2WL we see the wheel inertia effect (with only 3 touching) between 0.777 and 5.123 $g-cm^2$ gives 0.0452 s or 1.15 car lengths at the finish line on the "C" track and 0.0527 or 1.35 car lengths on the "I" track.



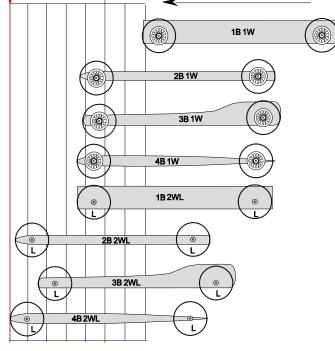


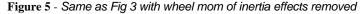
Figure 7 - How the cars as listed in Figure 1 fared at the finish line when only air drag effects were considered. The VR is Fig. 5.

WR Gravity Driven Virtual Racing _ □ × File Options Help								
Edit Track Parameters Trk: StdTrk_HOUSTON_C_BT "StdTrk_HOUSTON_C_BT", G=979.27, RHO=0.001225, SH=396.24, H=119.382, D=456.419, Type-C, UBT=1, Y0=0.511662, LP=930.666 (CGS units) (write protected)								
Run Car on Track Race Group of Cars Vary Car Parameter								
MAXI L(5.730)(3.13 ANY_CAR CAR_1B1W CAR_2B1W CAR_2B1W CAR_3B1W CAR_4B1W CAR_4B1W CAR_1B2W CAR_2B2W CAR_3B2W CAR_3B2W CAR_3B2W CAR_4B2W	Car CAR_4B2W CAR_2B2W CAR_3B2W CAR_1B2W CAR_4B1W CAR_4B1W CAR_2B1W CAR_3B1W CAR_1B1W	1.5784 1.5798 1.5819 1.6117 1.6121 1.6134	472.247 471.001 469.004 460.818 460.512 459.347	0.8267 0.8303 0.8360 0.8501 0.8510 0.8545	2.4051 2.4100 2.4179 2.4618 2.4631 2.4679	0.164 0.374 1.541 1.575 1.703		

Figure 3 - Race results for the standard circular arc ramped track.

VR Gravity Driven Virtual Racing								
Edit Track Parameters Trk: StdTrK_HOUSTON_LBT "StdTrK_HOUSTON_LBT", G=979.27, RHO=0.001225, SH=396.24, H=119.382, D=456.419, Image: StdTrK_HOUSTON_LBT" Typ=I, UBT=1, ITT=0, ALPHA=0.255831, S1=471.774 (CGS units) (write protected) Image: StdTrK_HOUSTON_LBT								
Run Car on Track Race Group of Cars Vary Car Parameter Selected cars for race: Car T1 V1 T2 TT Car Length								
□ MAXI L(5.730)(3.13] □ ANY_CAR ☑ CAR_1B1W	CAR 4B2W CAR_2B2W	1.9875	474.126	0.8226 0.8234	2.8108	0.030		
 ✓ CAR_2B1W ✓ CAR_3B1W ✓ CAR_4B1W 	CAR_3B2W CAR_1B2W CAR_4B1W	1.9909	471.714	0.8312	2.8220	0.328		
 ✓ CAR_1B2W ✓ CAR_2B2W ✓ CAR_3B2W ✓ CAR_4B2W 	CAR_2B1W CAR_3B1W CAR_1B1W	2.0297	462.172	0.8492	2.8789	1.846		

VR Gravity Dri File Options Help	ven \	virtual Racii	ng				_ 🗆 X		
Edit Track Parameters									
Typ=C, UBT=1, Y0=0.511	"StdTrk_HOUSTON_C_BT", G=979.27, RHO=0.001225, SH=396.24, H=119.382, D=456.419, Typ=C, UBT=1, Y0=0.511662, LP=930.666 (CGS units) (write protected) Run Car on Track Race Group of Cars Vary Car Parameter								
Selected cars for race		Car CAR_4B2WL CAR_2B2WL CAR_4B1W CAR_4B1W CAR_1B2WL CAR_2B1W CAR_2B1W	T1 1.6083 1.6086 1.6099 1.6117 1.6120 1.6121 1.6134	√1 463.946 463.638 462.462 460.818	T2 0.8408 0.8417 0.8452 0.8501 0.8508 0.8510 0.8545	2.4503 2.4551 2.4618 2.4628 2.4631 2.4631	0.158 0.334 0.360 0.367 0.492		



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<u>File O</u> ptions <u>H</u> elp							
Edit Track Parameter	s Trk: S	StdTrK_HOUSTO	N_I_BT				•
"StdTrK_HOUSTON_I Typ=I, UBT=1, ITT=0, A	ALPHA=0.2	255831, S1=471.7	74 (ĊGS	units) (writ	e protect		.419, 🔶
Run Car on Track	Race G	roup of Cars	/ary Ca	r Parame	eter		
Selected cars for ra	ace:						
CAR 1B1W		Car	T1	V1	T2	TT	Car Leng
CAR 2B1W		CAR 4B2WL	2.0247	465.595	0.8378	2.8624	
CAR 3B1W		CAR_2B2WL	2.0250	465.366	0.8385	2.8635	0.029
CAR 4B1W		CAR 3B2WL	2.0263	464.491	0.8414	2.8677	0.138
CAR_1B2W		CAR_4B1W	2.0281	463.267	0.8455	2.8736	0.293
CAR_2B2W		CAR_1B2WL	2.0283	463.087	0.8461	2.8745	0.315
CAR_3B2W		CAR 2B1W	2.0284	463.039	0.8463	2.8747	0.321
CAR_4B2W		CAR 3B1W	2.0297	462.172	0.8492	2.8789	0.432
CAR_1B2WL		CAR 1B1W		460.780			
CAR_2B2WL CAR_3B2WL							

Figure 6 - Same as Fig 4 with wheel mom of inertia effects removed