Real Hands-On Active Learning Activities in a Physics of Sports Class

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Outline of Talk

- Overview of the Physics of Sport class with some examples of topics and expectations

- Demonstration of a novel tool to conveniently spin-up beach balls or various balls of sizes used in athletic competition.

- Analysis of data taken by students using the spin-up ball tool to test a simple model of extracting the Magnus force lift coefficient C_L.

Overview of the
Physics of Sport Course PHYS 1130







Overview

- This course is a study of the motion of flying and spinning projectiles (humans too) in sports such as soccer, tennis, pickle ball, basketball, baseball, football, track and field, even dancing and ballet, etc.
- The course includes active participation by students to analyze the trajectories of the real motion of falling, spinning, and bouncing balls recorded on video.
- Graphs, videos and diagrams will be used extensively as well as simple pictures of how air flows around a spinning ball traveling through space.
- Math is used to calculate kinematics, forces, and projectile trajectories and to learn how different forces contribute to the motion of the ball in question and how energy is transferred between ball and player.



Why take this course?

General

- To get a better understanding of the game for fun and career too

Using physics knowledge to gain an advantage in sports

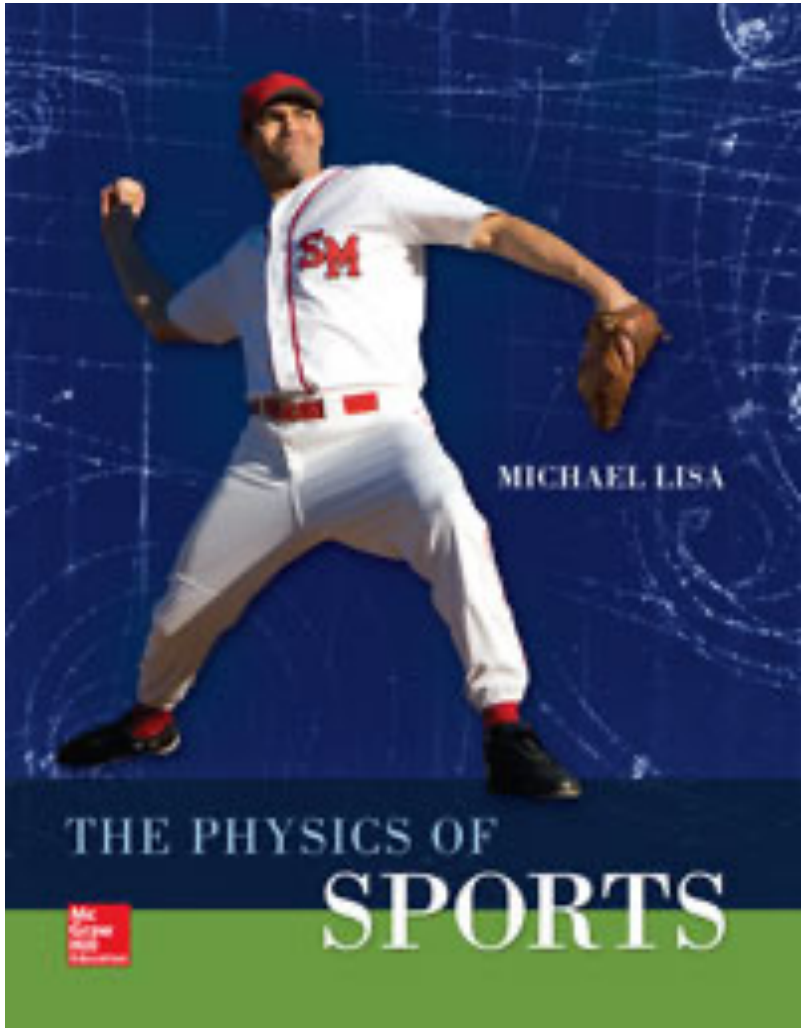
- In football the low man wins
- In basketball the importance of having the correct arc on your shot
- In baseball the advantage or disadvantage of sliding into first base
- In volleyball improve your float serve while at the beach

Technological reasons

- With a sports related physics course under your belt students have more opportunities for employment

A little Advertisement poster created by UVa summer session





We use a 400 page text covering a myriad of athletic topics - by Mike Lisa.
PHYS 1130 covers half the book - 200 pages.

- Non-calculus-3 cr-hr physics class
- Taught twice a year.
- Once in the summer in a 4-week session- in person
- Once in JTerm in a two-week session - online
- I’ll focus on the summer session in this talk.

- All Assignments are graded - include:
  - Reading followed with graded Quiz 3 times a week
  - Summative weekly quizzes
  - Six Homework Problem sets - one a week
  - 4 activity reports due on Thursday once a week
  - Attendance and class participation is graded
  - Midterm and final exam

It’s not a gut course

Contribution towards final grade

- Reading homework that is graded and due 3 times a week--------10%
- Quizzes due once a week on Thursdays---------- 10%
- Six Homework Problem sets due roughly once a week----------20%
- 4 activity reports due on Thursday once a week----------20%
- Attendance and class participation ----------0%
- Midterm and final exam----------40%

- The average range of grades the past few years is B+ in the summer session and B+ to A- in JTerm.

Class Projects

In the last summer session the 4 major projects were:

The main point in each was to determine the:

- Hangtime t
- g in freefall
- Magnus Coefficent C_L
- Coefficient of Restitution (COR) and Impulse J

and comparing with known values

The rest of the talk will focus on the Magnus Effect.

- What parameters do we need to know due to study the Magnus effect and determine the lift coefficient?

  - mass of the skin, mass of the air, diameter of the ball
  - an area to drop a spinning ball from a large height
  - mechanism to spin the ball
  - map its trajectory and determine its spin rate

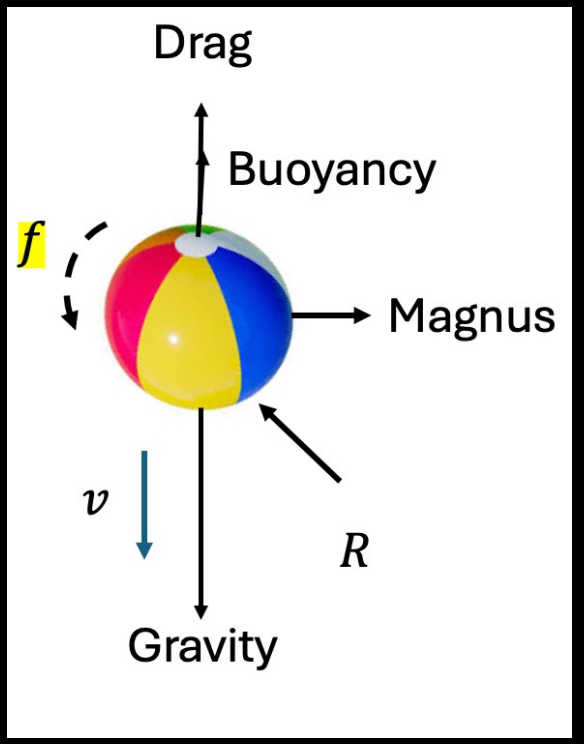
  One can spin a ball by hand or using our novel spin-up apparatus. Here it is


this one
DELTA
ON
REMOVE TO LOCK
OFF

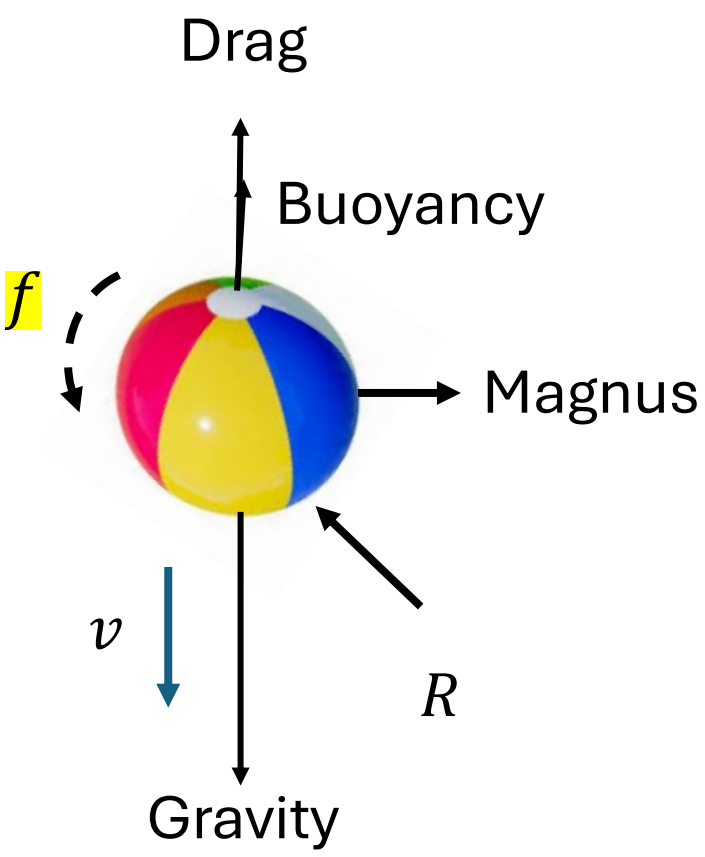

SPEEDBALLS ABEC 9 EARTHWINDS
VIPER BALLS 63 MM
RAGE 63 MM

Here is a vivid demonstration of the Magnus Effect that got us all interested.





Forces acting on a spinning B each Ball dropped from rest



$$\vec{F}_B = \rho V g$$

$$\vec{F}_D = -CD(\rho A)|v|(\vec{v})$$

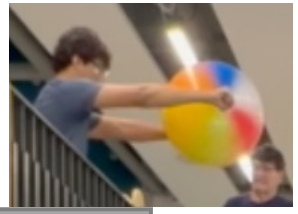
$$\vec{F}_{geff} = m\vec{g}_{eff} = (1 - \rho V/m))\vec{g}$$

ρ — density of air
R - radius of ball
v - velocity of ball
$A=\pi R^2$
$\vec{\omega}$ angular velocity of ball
V=volume of a sphere
m=mass of skin + mass of air

$$\vec{F}_M = \frac{\pi}{2} C_L \rho R^3 \ \vec{\omega}\times\vec{v} \quad C_L = 0.1$$ Lisa model

$$\vec{F}_M = \pi^2 C_L \rho R^3 \frac{\vec{\omega}\times\vec{v}}{|\omega|} \quad C_L = \frac{1}{2+\frac{v}{R\omega}}$$ Nathan model

$$F_{net} = \vec{F}_{geff} + \vec{F}_D + \vec{F}_M$$

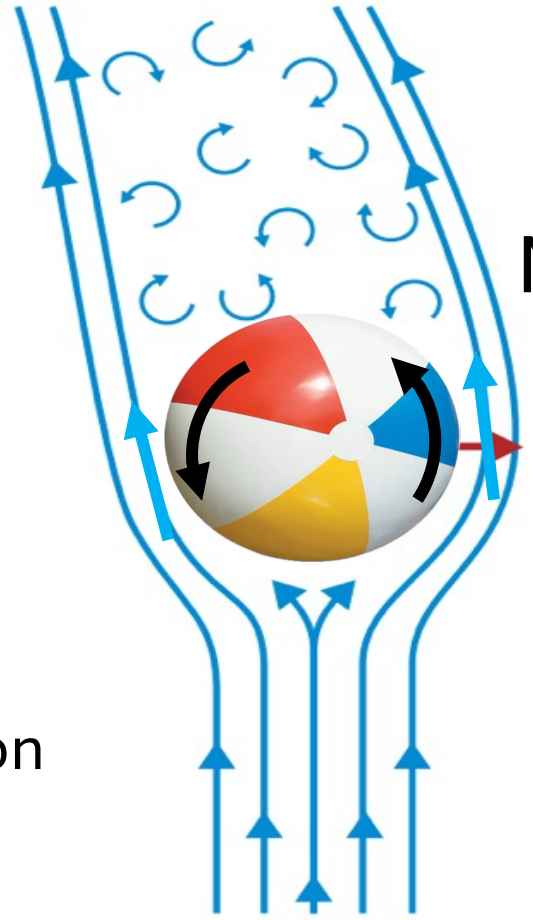


Ball
Directio



No Spin

Ball
Direction



Magnus Force

Spin direction Counter-Clockwise

Example of student B during class spinning up a 16 in diameter beach ball

Typical parameters

- Radius ----------0.203 m
- Spin rate ----------6.25 rps
- Angular velocity ---------- 39.25 rad/s
- Surface speed ———— –7.97 m/s
- Average vertical velocity ----3.51 m/s
- Drop height ----------5.01 m
- Lateral displacement -------2.09 m
- Drop time ----------1.80 s



Project 3 Determine the Lift Coefficient C_L

From $\left|\vec{F}_M\right| = \pi^2 C_L \rho_{air} R^3 v f = m a_x$ solve for C_L

$$C_L = \frac{m a_x}{\pi^2 \rho_{air} R^3 v_{avg} f}$$

1. The total mass m, ρ_{air} and R^3 are easily obtained. The mass of the skin of the beachball is determined be weighing the ball without air. After inflation the air pressure is measured and the gas law is used to determine the mass of the air.

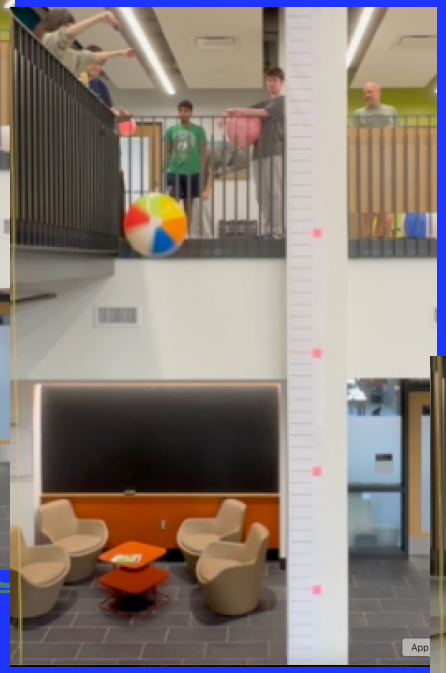
2. a_x is determine $a_x = 2\ x/t^2$ assuming a_x is approximately constant. Measure x from the grid on the video replay calibrated using the 16 in ball. Time is obtained from the digital clock and iphone camera which should agree. They do.

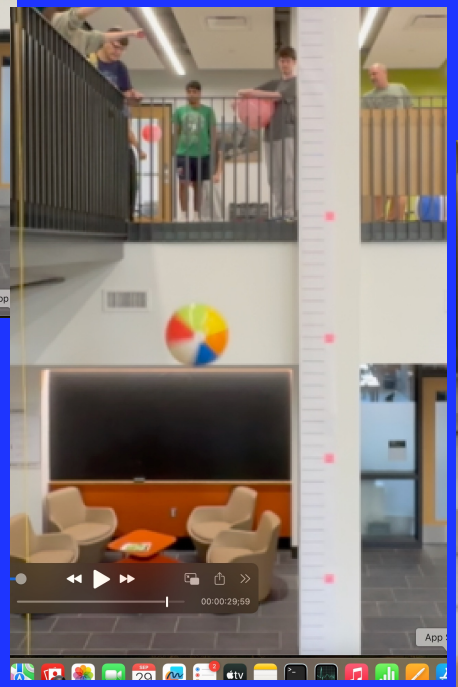
3. v_{avg} is determined from $v_{avg} = \frac{1}{2}\sqrt{2a_y y}$ where y is the distance the ball is dropped.

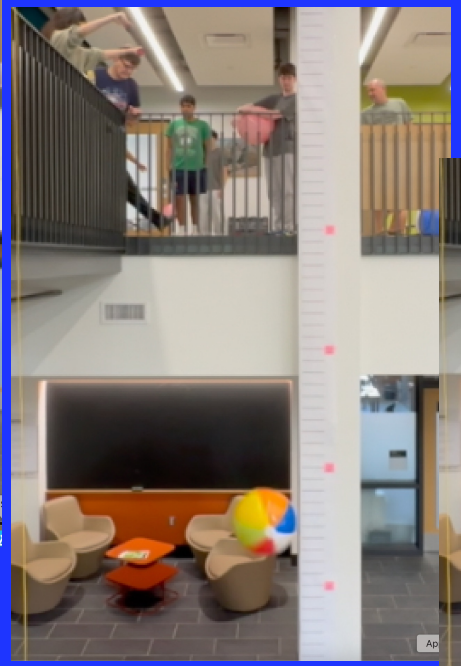
4. The acceleration a_y is determined from $a_y = 2y/t^2$ and should agree with the expected reduction due to buoyancy $g_{eff} = (1 - \rho_{air} V/m)g$ where m is the mass of the balloon skin plus mass of the air inside the ball.

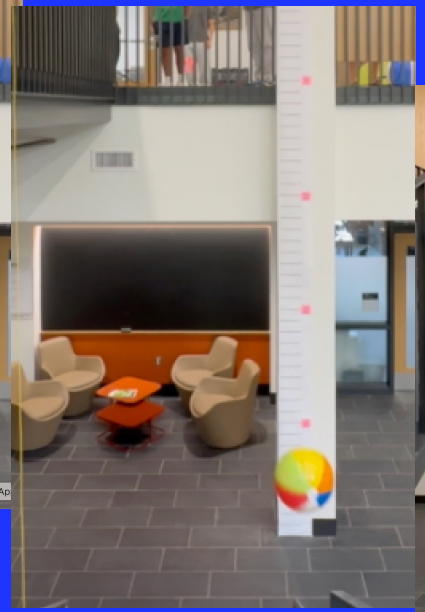
5. f the rotational frequency is measured using the known frame rate and slowing down the video so you count the rainbow colored rotations over a fixed time interval.

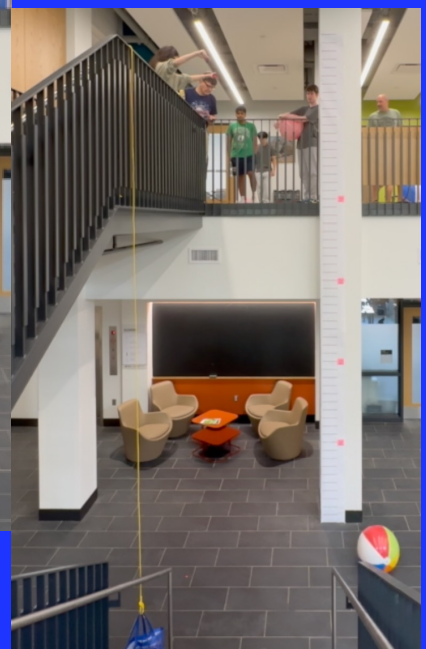




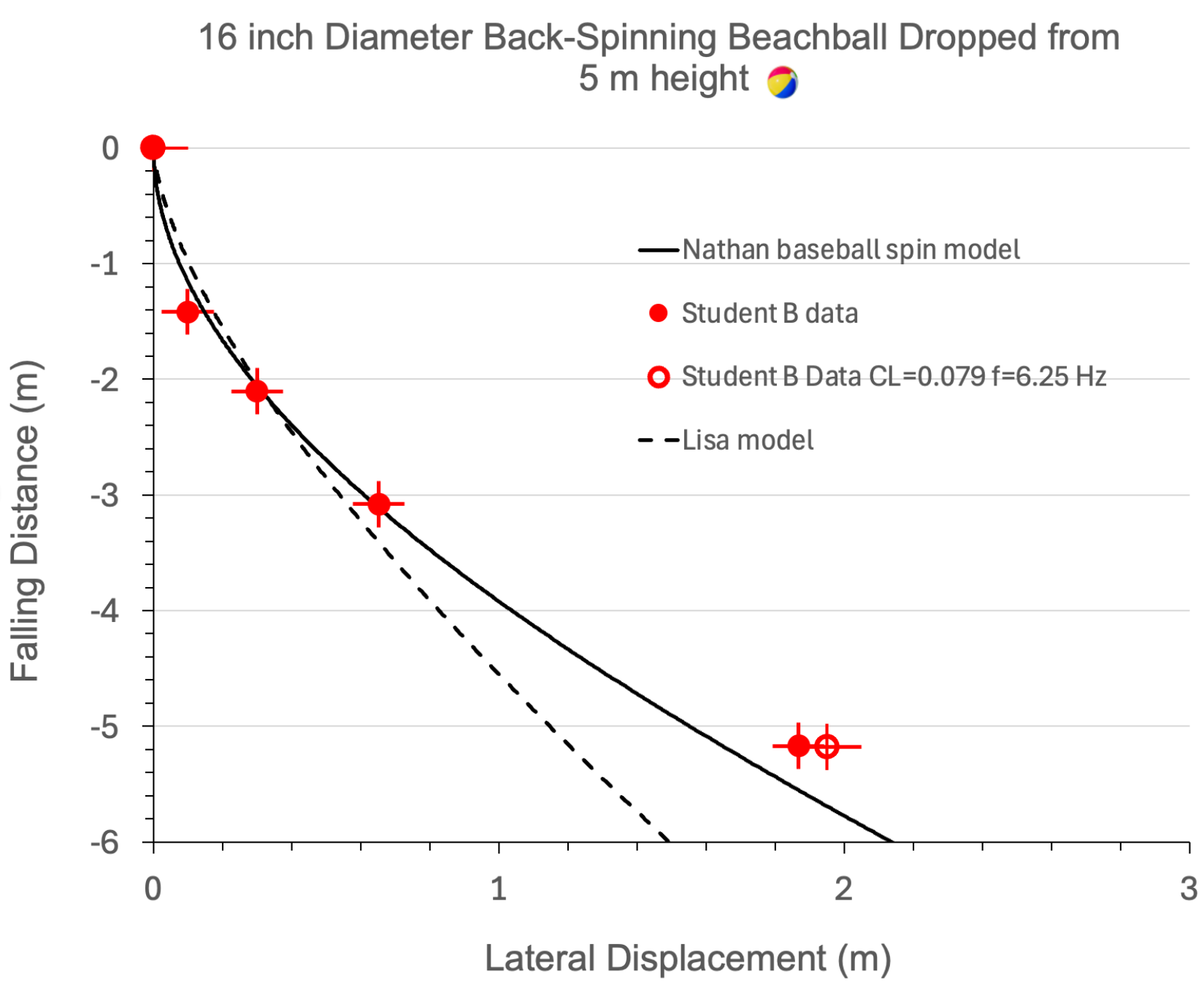


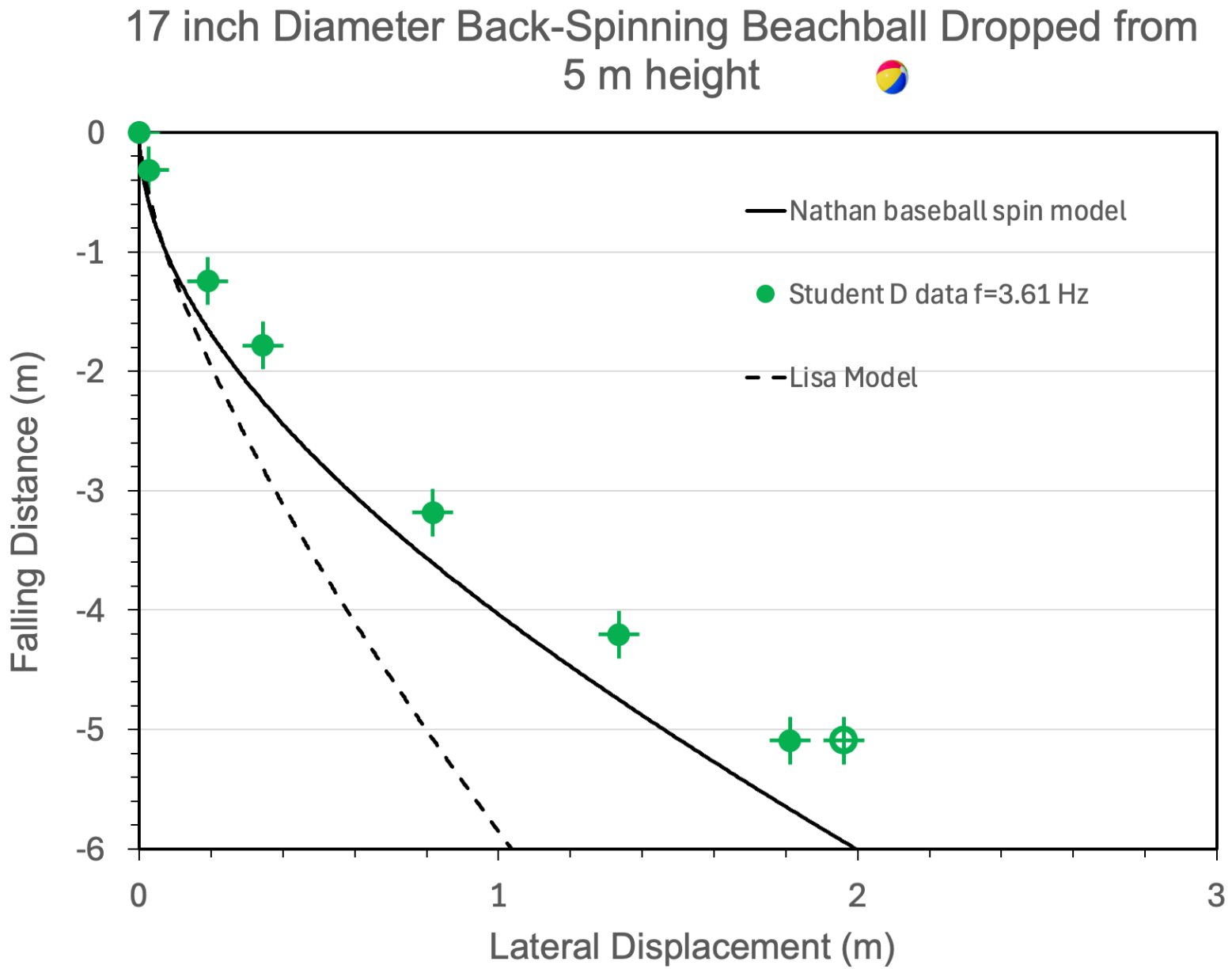






- Ball Radius ----------0.203 m
- Spin rate ----------6.25 rps
- Angular velocity ---------- 39.25 rad/s
- Surface speed ——————— —7.97 m/s
- Average vertical velocity ----1.75 m/s
- Drop height ----------5.01 m
- Beach ball hits the floor-----2.09 m
- Drop time ----------1.80 s


16 inch Diameter Back-Spinning Beachball Dropped from 5 m height
Falling Distance (m)
0
-1
-2
-3
-4
-5
-6
0
1
2
3
Lateral Displacement (m)
Nathan baseball spin model
Student B data
Student B Data CL=0.079 f=6.25 Hz
Lisa model


17 inch Diameter Back-Spinning Beachball Dropped from 5 m height
Falling Distance (m)
0
-1
-2
-3
-4
-5
-6
0
1
2
3
Lateral Displacement (m)
Nathan baseball spin model
Student D data f=3.61 Hz
Lisa Model

Results C_L for from the Students- Expected value C_L=0.1

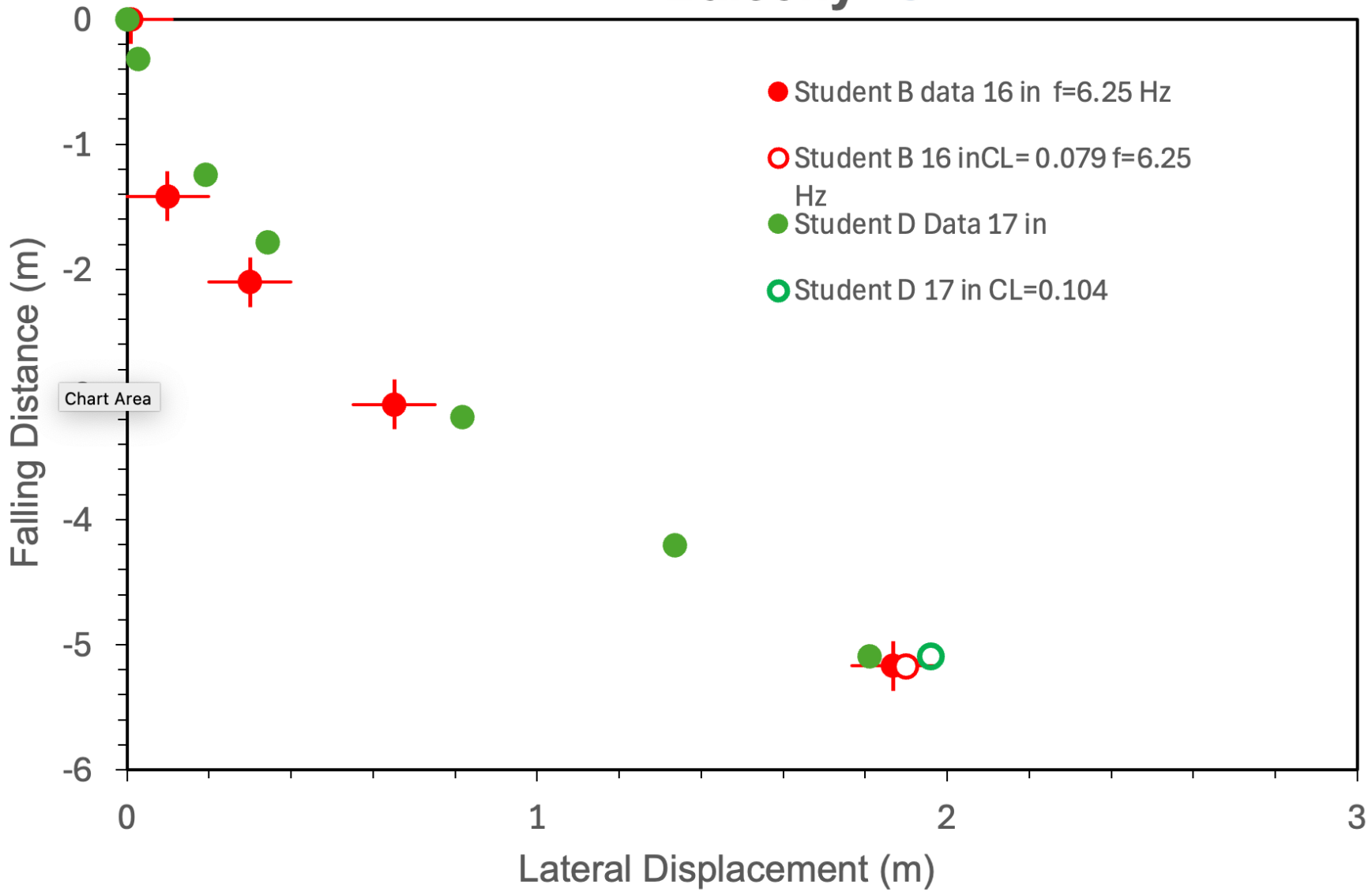
$$C_L = \frac{2m}{\pi^2 \rho_{air} R^3} \left(\frac{d\, v_{y\,ave}}{f h^2}\right)$$

Student Group	Mass m kg	ρ_{air} 1.2 kg/m^3	R m	D m	$v_{y\,ave}$ m/s	f s^{-1}	h m	C_L	C_L check
F	0.0865	1.2	0.216	2.06	4.87	7.027	5.01	1.35	0.082
E	0.086	1.2	0.203	2.723	3.55	7.29	5.01	0.097	0.092
D	0.0865	1.2	0.216	2.040	3.200	3.610	5.010	0.104	0.105
C	0.0865	1.2	0.203	2.438	3.520	6.220	5.010	0.094	0.098
B	0.0846	1.2	0.2032	2.090	3.509	6.250	5.010	0.0796	0.080
A	0.053	1.2	0.1	1.100	4.720	15.040	5.010	0.116	0.123

Conclusions Using Beach Balls for testing Magnus model with students

- Need a more efficient tool extract x and y position and with a little more accuracy
- Need more control over spinning small balls in general and up to higher frequencies with all balls.
- Activity consumes lots of time and requires 4 staff to over see the students,
- Fit trajectory using spin and velocity dependent C_L and correct for velocity dependent changes in C_D
- It definitely raises students' enthusiasm for the subject.

Comparison between 16 in and 17 in Back Spinning Beach Ball Dropped from Rest from a 5 m High Balcony



A picturesque summary of topics



Project 3 Determine the Lift Coefficient C_L by the students

An (iphone not shown in the picture) is mounted on a tripod on the stairwell about 12 feet from the plane of motion and about 6-7 feet off the floor.

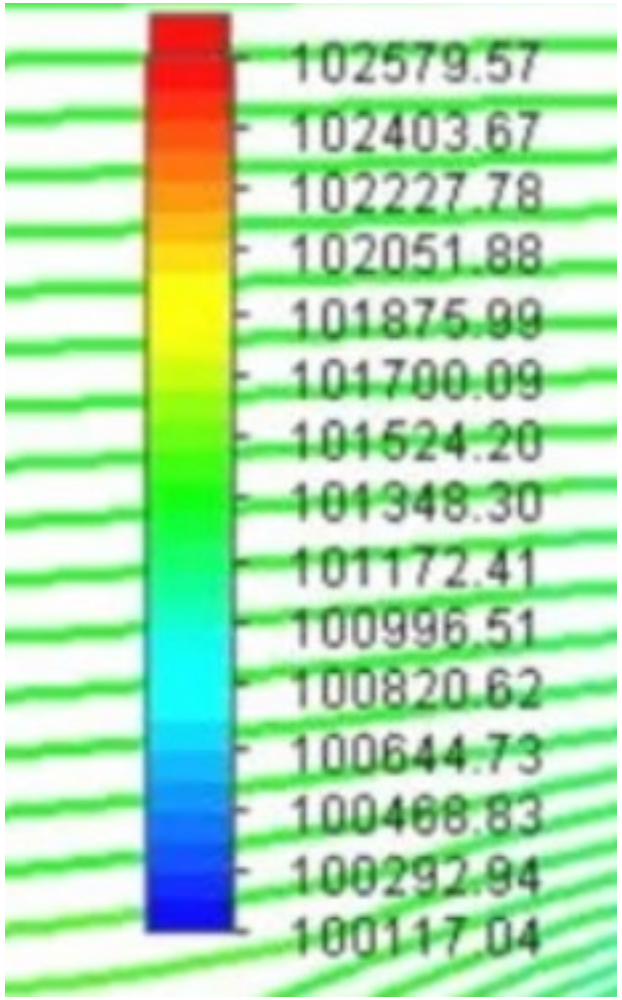
Students work in pairs. One student will release the ball with backspin using our “spin it up tool” and the other student will locate the spot on the floor where it was struck by the ball.

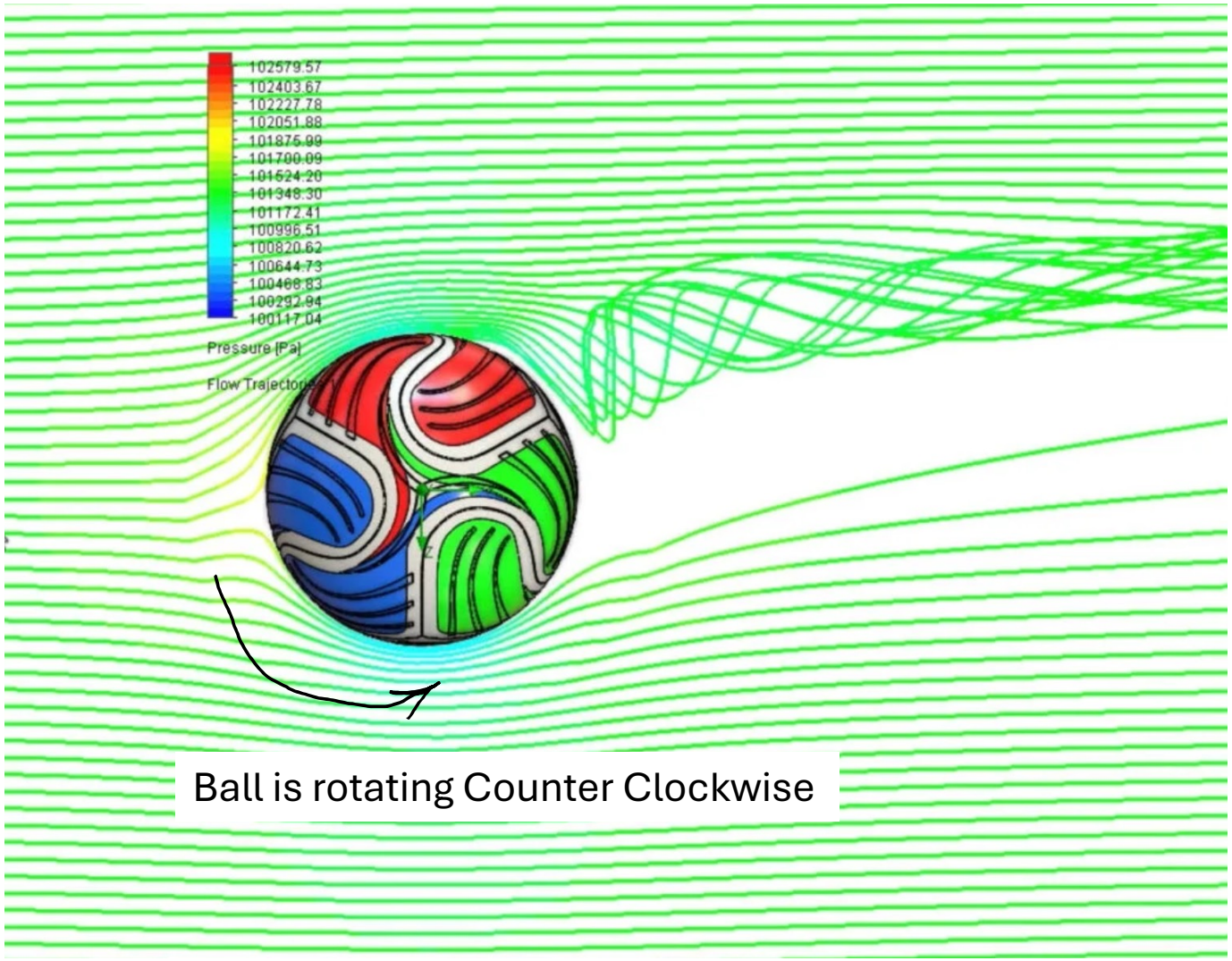
After recording the dropped ball students transfer the video to imovie and replay it to determine the fall time accurately and measure x and y distances on the floor using the floor tiles as calibration. The ball itself was also used as a calibration tool.



Solving the Napier-Stokes Equation in a mesh around the ball in millions of cells by Solidworks – an expert company in flow simulation studies- Shows pressure difference around the ball and therefore the lateral force scales with angular velocity

Pressure in Pascals





Ball is rotating Counter Clockwise

10:30 – 11:35, Break 5				PHYS 1130 The Physics of Sport Summer Session III -	Reading	SB / HW
11:40 – 12:45		Time		Topics and times may be adjusted as we go	Connect	Connect
Date	Time-Day	min	Lecture	Topics	Chapters	Due
7-12	10:30 -Mon	60	1	Course organization, projectile motion, and activities	1.1-1.3,	
7-12	11:40 - Mon	60	2 Dem	Kinematics of motion: speed and acceleration	1.3, 2.1, 2.2	SB1.1, SB2.1
7-13	10:30-Tue	60	3	How acceleration of gravity affects hangtime	2.1-2.3	
7-13	11:40-Tue	60	Activity	Project 1 : PR01 Activity to determine your hangtime.		PR01
7-14	10:30-Wed	60	4	How do you find your hangtime or a ball thrown in the air?	2.3	SB3.1-SB3.3
7-14	11:40-Wed	60	5	How much force do you need to jump 40 in. off the floor?	3.1 - 3.3	HW01
7-15	10:30-Thu	60	6	Why bend your knees when landing?	3.2.4, 3.2.5	PR01 Due
7-15	11:40-Thu	60	Dem	Discussion and PR01 due and QZ01 12:15 – 12:45	1.1-3.2	QZ01
7-16	10:30-Fri	60	7 Dem	How lineman in football use static friction to gain an advantage	3.3	SB3.4-SB3.5
7-16	11:40-Fri	60	8	The mystery of Curling, Crouching in football. The low man wins	3.4-3.5	
7-19	10:30 -Mon	60	9	Centripetal force, the rotor, racing around curves, thrown against the door	3.5	HW02NUMC
7-19	11:40-Mon	60	10 Dem	Punting in football - timing between gunner and ball. Long jump	4.1 – 4.4	SB4.1-SB4.4
7-20	10:30 Tue	60	11	Effect of buoyancy air. baseballs, basketballs, soccer ball, beach ball	5.1 - 5.2	SB5.1-SB5.3
7-20	11:40-Tue	60	Activity	Project 2 : PR02 Activity to study the acceleration of a falling ball		PR02
7-21	10:30-Wed	60	12 Dem	Aerodynamics of the Drag Force on objects flying through air	5.3	SB.5.4-5.6
7-21	11:40-Wed	60	13	Do threads on baseballs and dimples on golf balls affect flight?	5.4	HW03NUMC
7-22	10:30-Thu	60	14 Dem	Drag Crisis:Reduction of the turbulent wake behind the ball	5.4 - 5.5.4	PR02 Due
7-22	11:40-Thu	60	Dem	Discussion and PR02 due and QZ02 12:15–12:45		QZ02
7-23	10:30-Fri	60	15	How the Magnus force affects baseballs and soccer balls	5.4.2-5.5.1	
7-23	11:40-Fri	60	Midterm	Midterm Exam 11:30 -12:45	1 – 4	Midterm

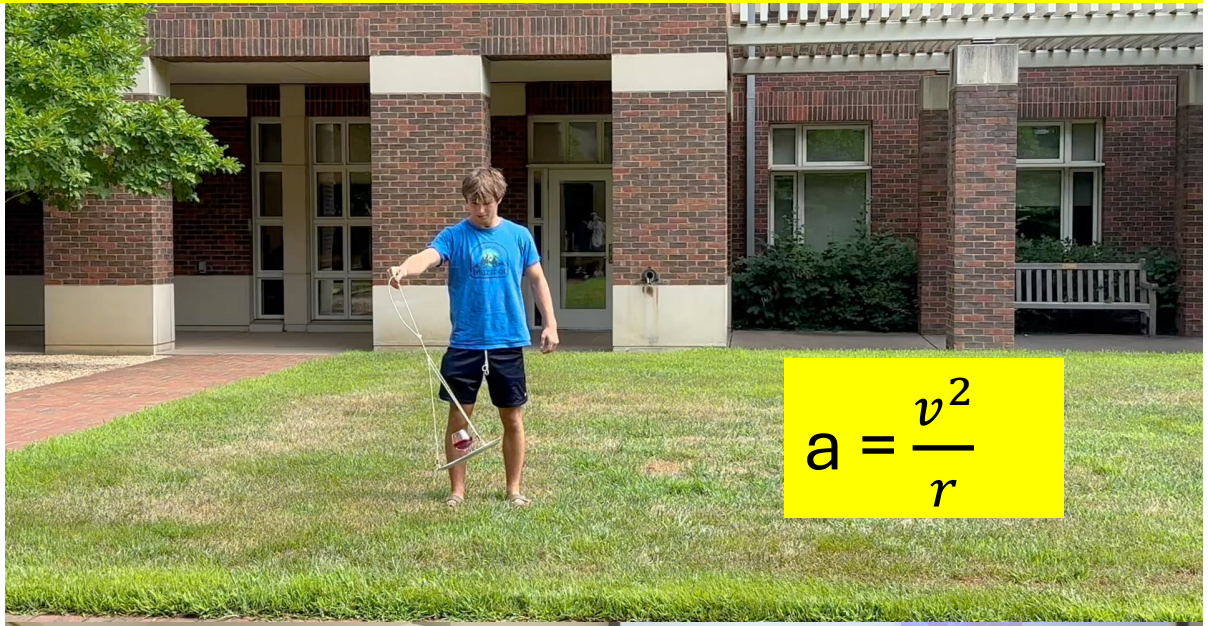
Player from my class being video recorded shooting a Free Throw by another player in the class.



Tracking the basketball from the video of a 6 ft 9 in student from my class shooting a free throw. “Nothing but Net”.

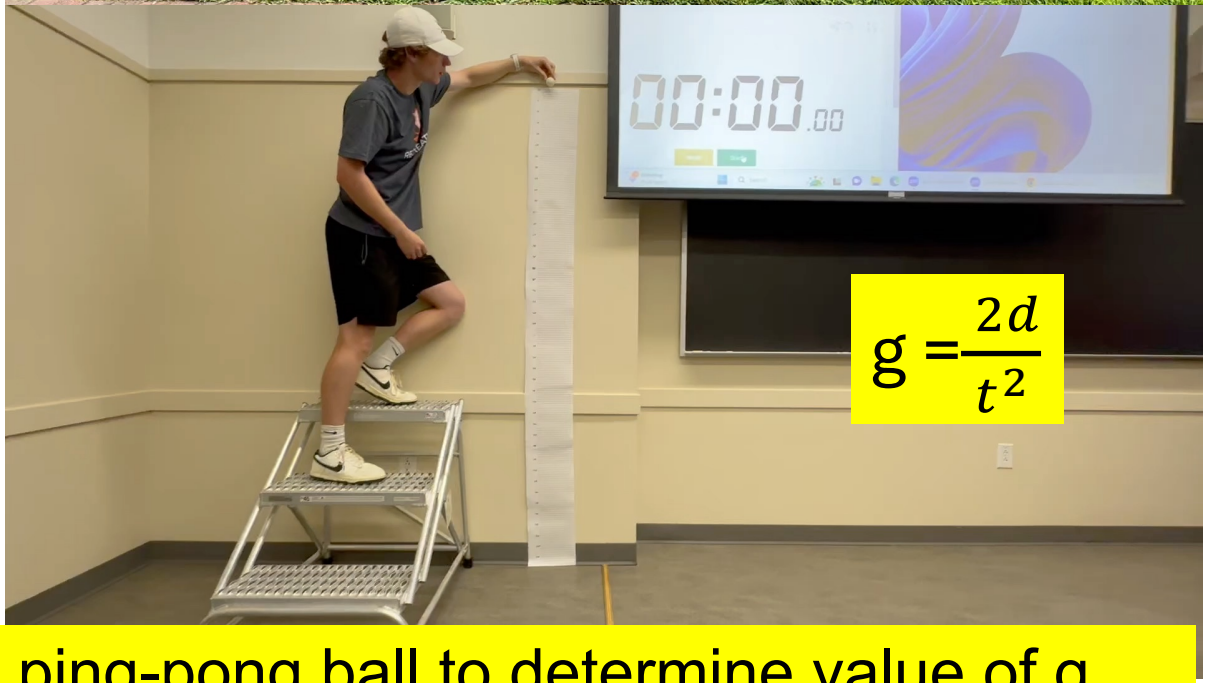
Measuring swinging frequency and radius of circle to get orbital acceleration





$$a = \frac{v^2}{r}$$





$$g = \frac{2d}{t^2}$$

Measuring drop time of pickle ball and ping-pong ball to determine value of g

Student comments from evaluations

- Great Class but formulas are simple kinematics – kind of boring. However, activities are much more interesting.
- Formulas are beyond my knowledge of physics but activities I can do and make it all worthwhile.
- Many positive comments I won’t list them all

Summer Projects last summer

- Project 1: Students determine their hangtime and launch velocity using a force plate. (Photo of students jumping off force plate- Ying has some)

- Project 2: students extract the acceleration of gravity from data by dropping balls of different sizes. Students finally realize in some cases that buoyancy must be taken into account and maybe drag. Photo -Ying

- In Project 3: Slowing down the motion. Students use their iPhone to video record large spinning beachballs dropping slowly off the 2nd floor to determine the lift coefficient due to the Magnus force. Need Photo of motor and skate board wheels apparatus – AL

- Project 4: Students determine the Coefficient of Restitution of a bouncing balls using Force Plate.