Beach Ball Physics

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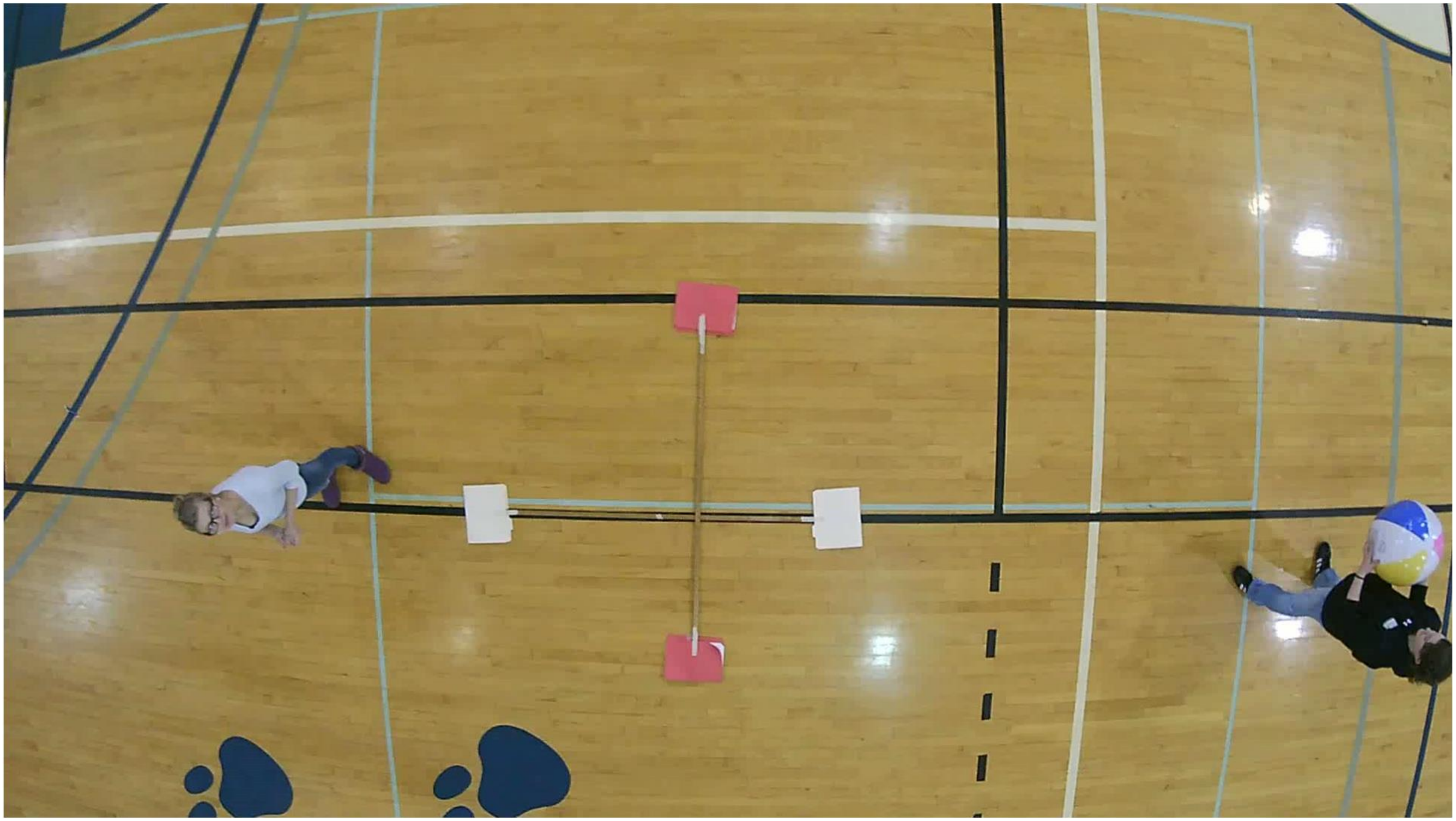
When discussing how to throw a wicked curve ball, “Bend it Like Beckham” or just those falling objects that don’t keep up, Beach Balls provide a convenient mechanism to explore the nonideal features that can arise in projectile motion. A Beach Ball’s motion can be understood in terms of weight, drag, buoyancy and the Magnus effect. This presentation shows some ways the motion of a Beach Ball in introductory mechanics labs, both as a departure from ideal free fall behavior and as a detailed exploration of friction and drag. Several short demonstration videos of Beach Balls in flight will also be shown. An interactive 3D simulation of Beach Ball trajectories which illustrates the roles of the various forces in the ball’s projectile motion will also be demonstrated. This presentation makes use of the Tracker video analysis program and the Easy JavaScript Simulations package, both from Open Source Physics (www.opensourcephysics.org).

PennState
Schuylkill

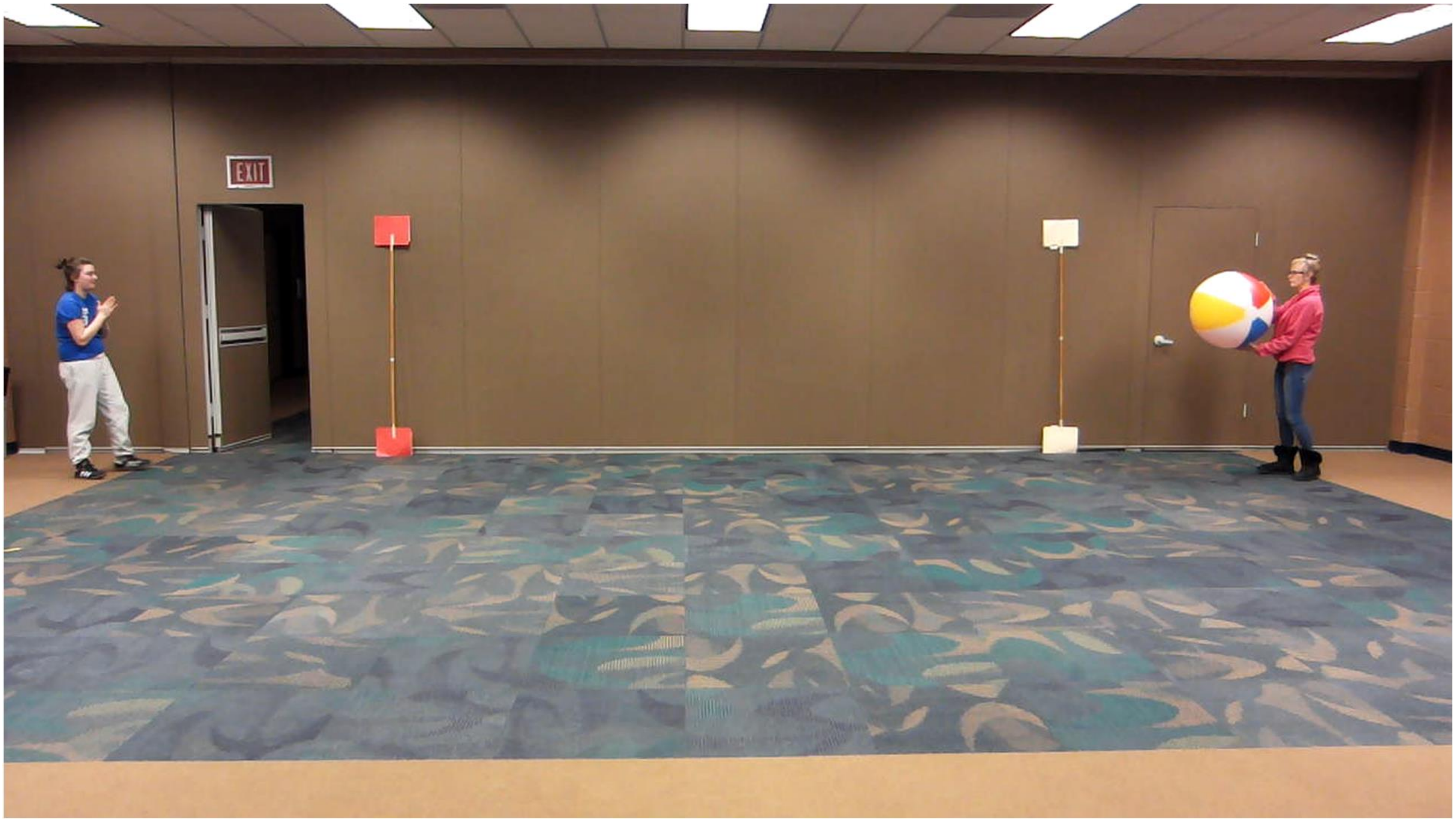
Example: Curve 1

Example: Curve 2

Example Curve 3:



Example Loft



Vertical Loop (1/4 speed)

A Brief Timeline

- Video Analysis: vertical motion, video analysis and g
  - Basketballs: good consistent expected results
  - Added lighter balls (yoga balls, beach balls)
    - “fairly” parabolic, but acceleration much less than g
      - buoyancy
    - Drag coefficient from terminal velocity!
    - Spin
      - control problem (Magnus)
      - Tracker autotracking problem (with striped beach ball)
  - “Complete” model: gravity, buoyancy, drag, Magnus effect
    - Demos: floater, sinker, curve ball
  - Most video analysis done with 120 fps video

The Physics of Beach Ball Flight

$$(m_{ball} + m_{air})\vec{a} = -(m_{ball} + m_{air})g\hat{z} + m_{air}g\hat{z} - \frac{1}{2}C_D\rho A v\vec{v} + \rho C_{spin}\, r_{ball}^3\vec{\omega} \times \vec{v}$$

- $g_{effective} = \frac{m_{ball}}{m_{ball}+m_{air}} g$ for low drag, no spin trajectories
- Terminal velocity and drag coefficient for no spin vertical motion:

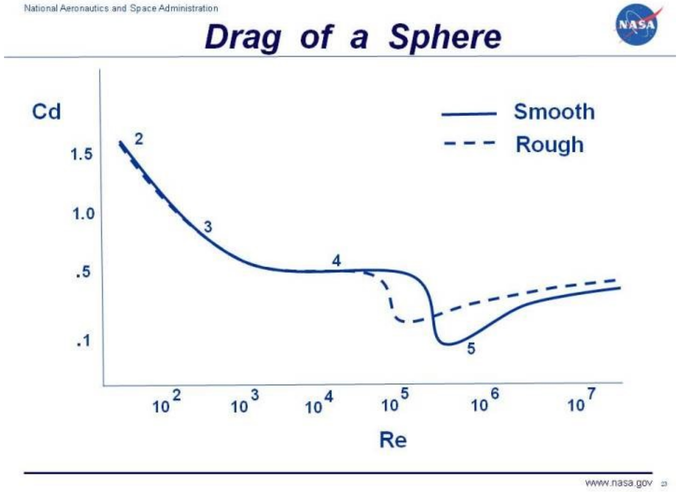
$$C_D = \frac{2m_{ball}g}{\rho A v_T^2}$$

Typical values for C_D .3 to .7, ideal smooth sphere C_D = .48

The Model *is* Limited (drag crises)

https://www.grc.nasa.gov/www/k-12/airplane/dragsphere.html

Drag and Lift are related



Parameter Fitting with Tracker

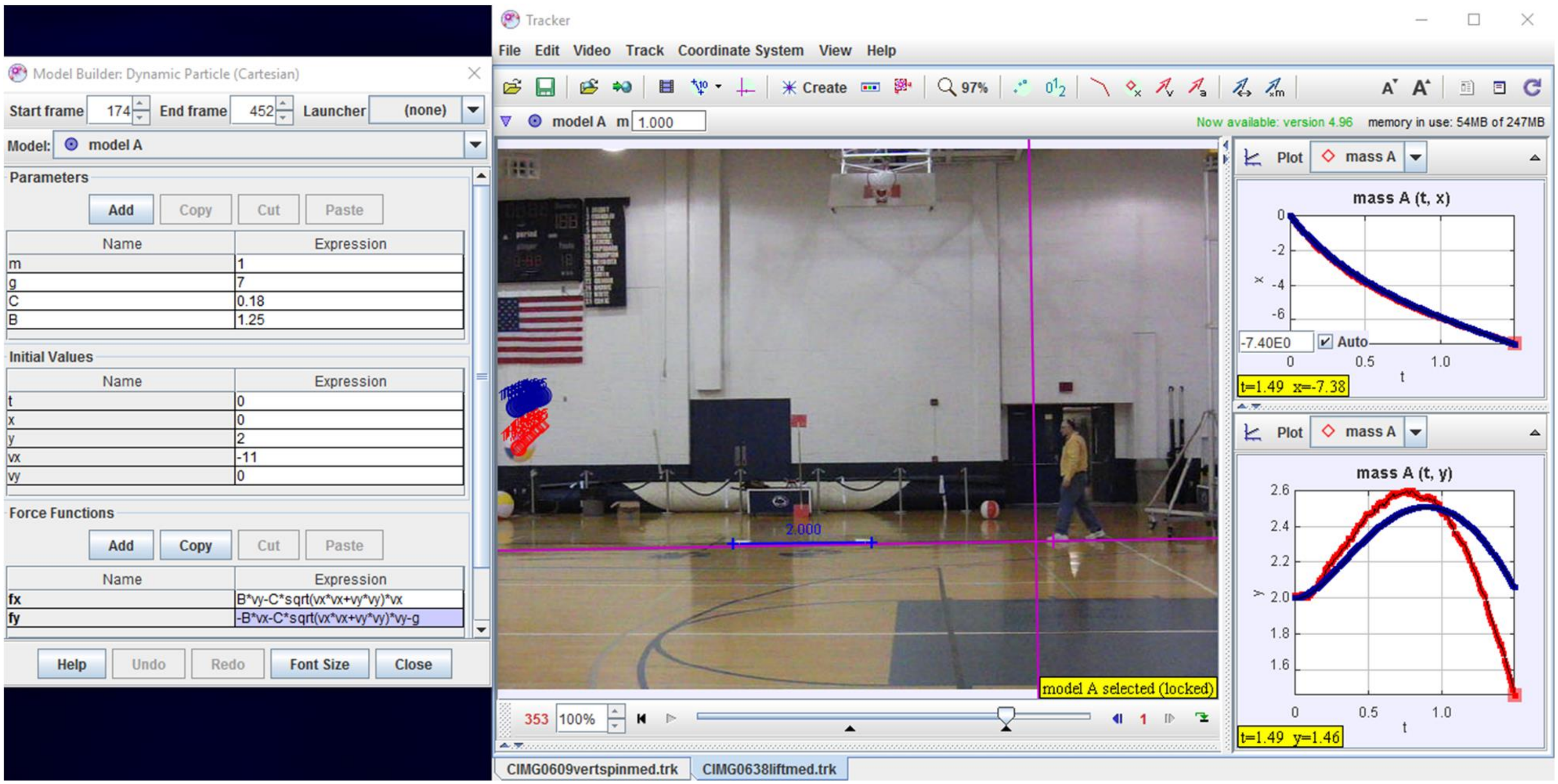
$$(m_{ball} + m_{air})\vec{a} = -(m_{ball} + m_{air})g\hat{z} + m_{air}g\hat{z} - \frac{1}{2}C_D\rho A v\vec{v} + \rho C_{spin}\, r^3\vec{\omega} \times \vec{v}$$

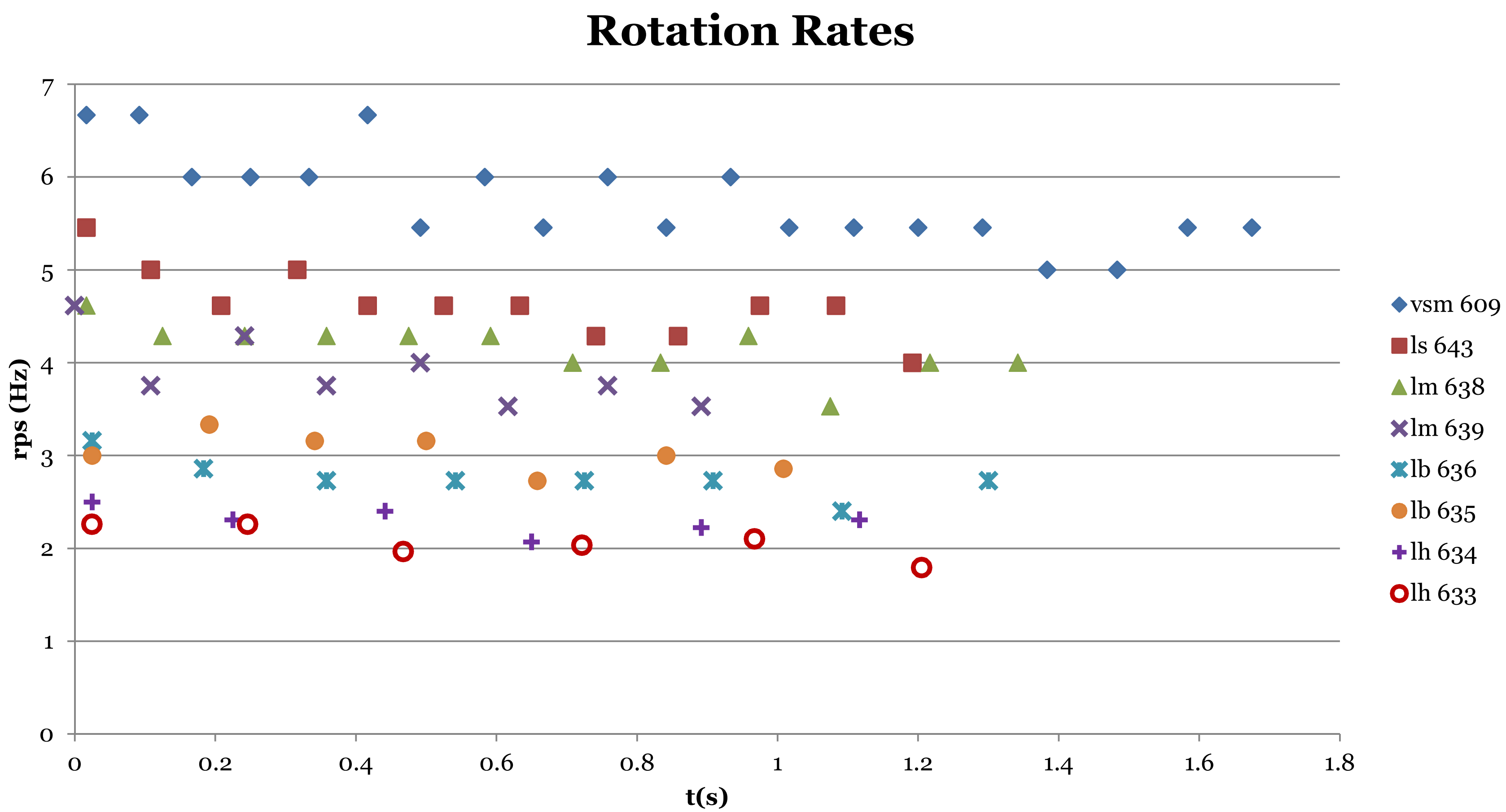
$$\vec{a} = -\frac{m_{ball}}{m_{ball} + m_{air}}g\hat{z} - \frac{C_D\rho A}{2(m_{ball} + m_{air})}v\vec{v} + \frac{\rho C_{spin}\, r^3\omega}{m_{ball} + m_{air}}\widehat{\omega} \times \vec{v}$$

$$\vec{a} = -g^*\,\hat{z} - Cv\vec{v} + B\widehat{\omega} \times \vec{v}$$

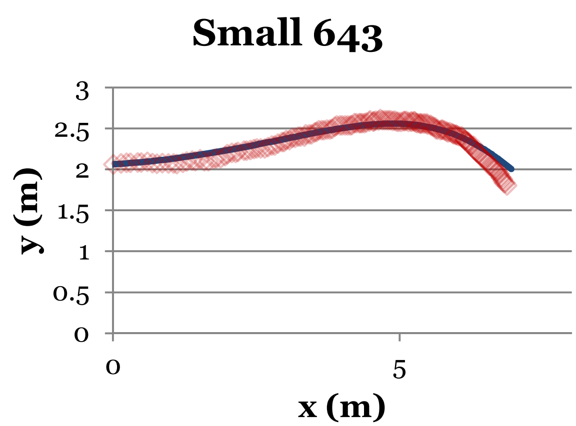
1. Calculate g^* from ball's mass and radius as well as the density of air
2. Initial x, y, v_x, v_y from position data
3. Tweak C, B to match trajectory (x-t, y-t, v-t graphs)
4. Track orientation of ball (every 1/2 rotation) to measure spin
5. Calculate C_D, C_{spin} from C, B, ω

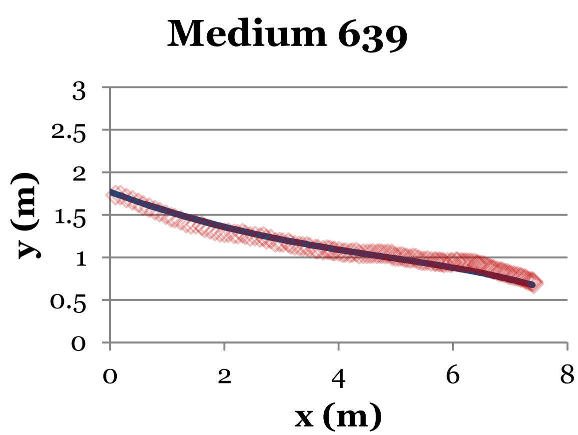
Parameter Fitting with Tracker

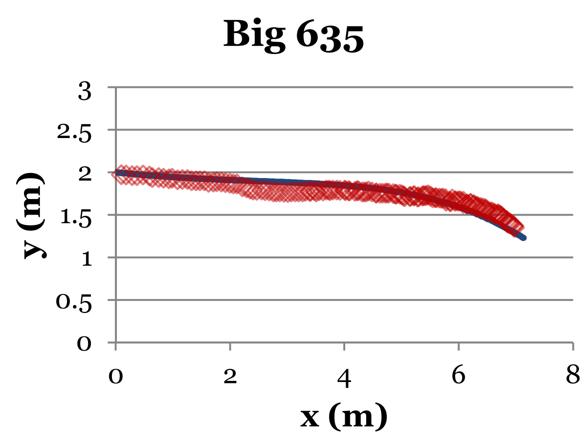


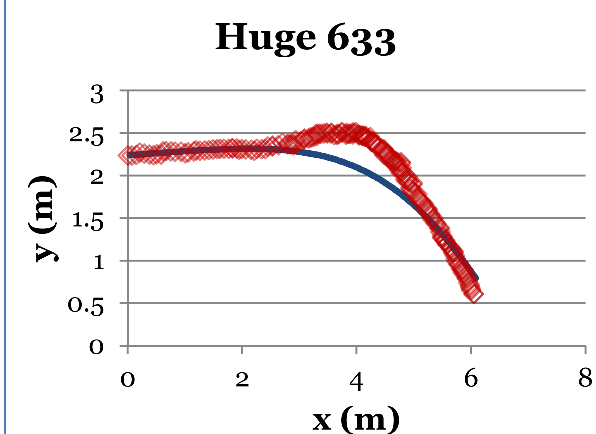

Rotation Rates
rps (Hz)
t(s)
0
1
2
3
4
5
6
7
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
vsm 609
ls 643
lm 638
lm 639
lb 636
lb 635
lh 634
lh 633

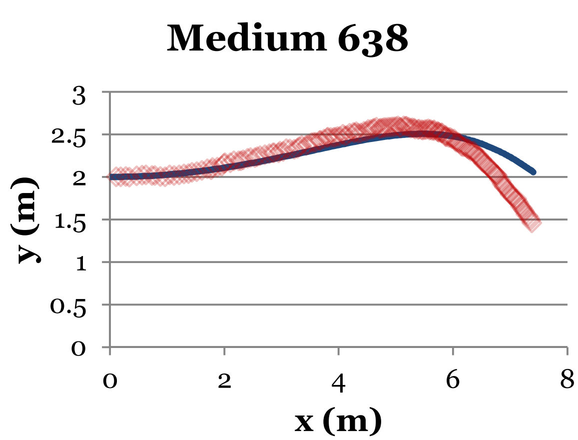
Parameter fit modelled paths from Tracker:
backspin lift trajectories

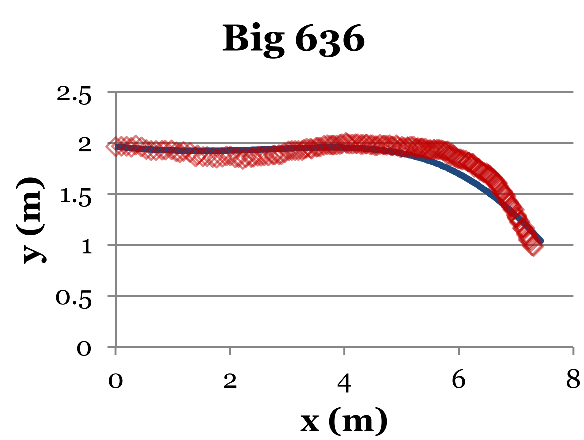


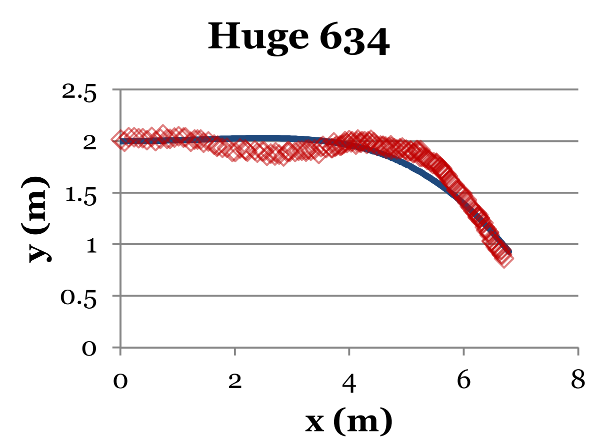










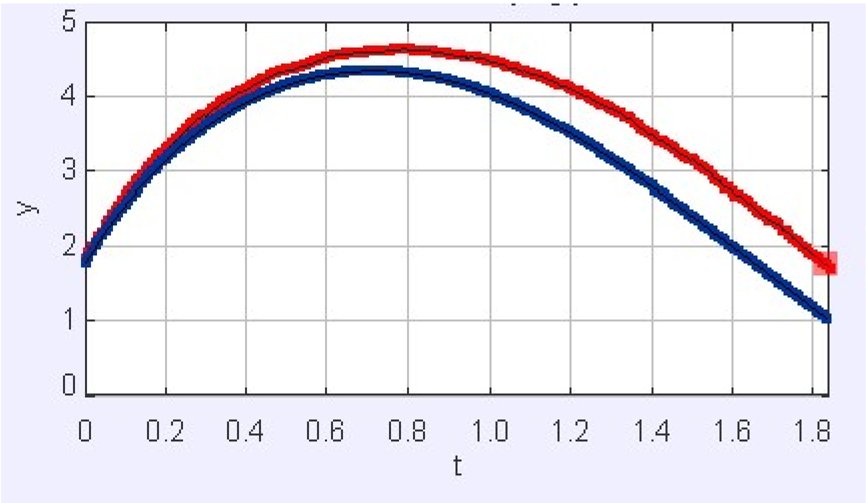


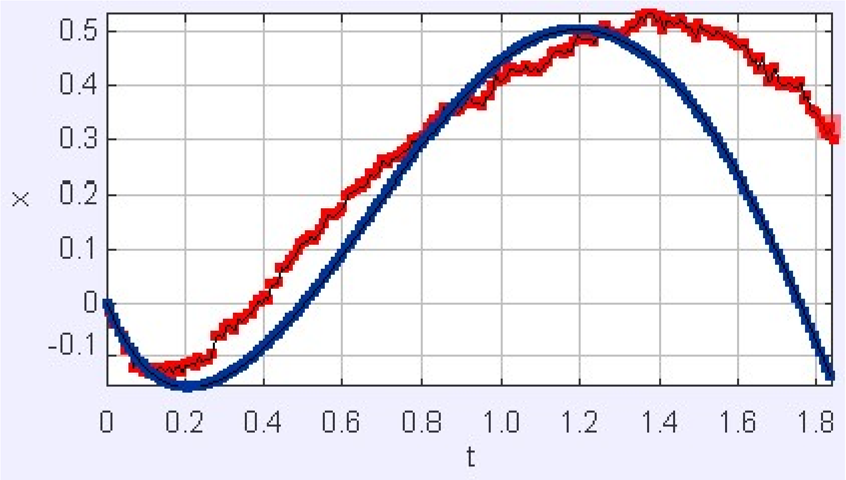
Back Spin Lift Parameter Results

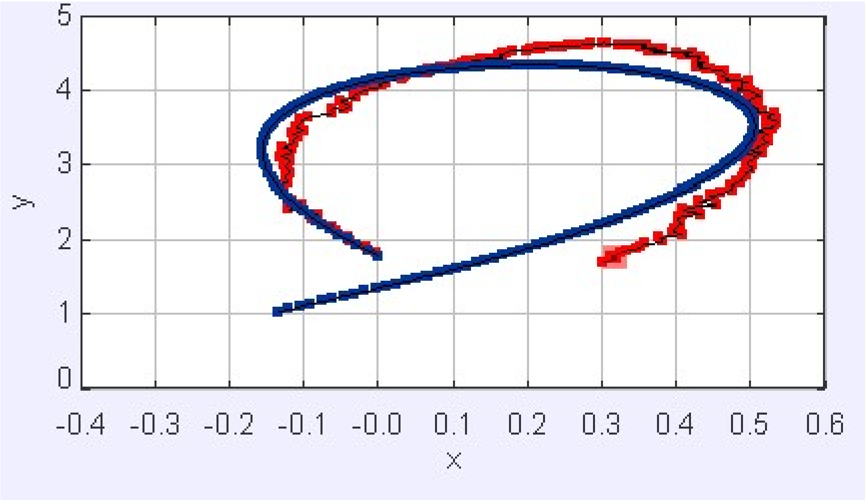
	small 643	medium 638	medium 639	big 635	big 636	huge 634	huge 633
radius (m)	0.17	0.20	0.20	0.29	0.29	0.41	0.41
m_{ball} (kg)	0.0786	0.1070	0.1070	0.2251	0.2251	0.4581	0.4581
m_{air} (kg)	0.026	0.043	0.043	0.12	0.12	0.35	0.35
$g_{effective}$ (m/s^2)	7.4	7.0	7.0	6.3	6.3	5.6	5.6
parameter fit							
C (1/m)	0.21	0.18	0.145	0.13	0.2	0.195	0.25
B (1/s)	1.18	1.05	1.25	0.67	1.05	0.82	0.7
rps (1/s)	4.62	4.14	3.87	3.02	2.74	2.29	2.06
physical parameters							
ω	29.03	26.01	24.33	18.99	17.24	14.41	12.92
Cd	0.39	0.34	0.27	0.28	0.44	0.49	0.63
Cspin	0.68	0.59	0.75	0.42	0.72	0.55	0.53

Vertical Loop

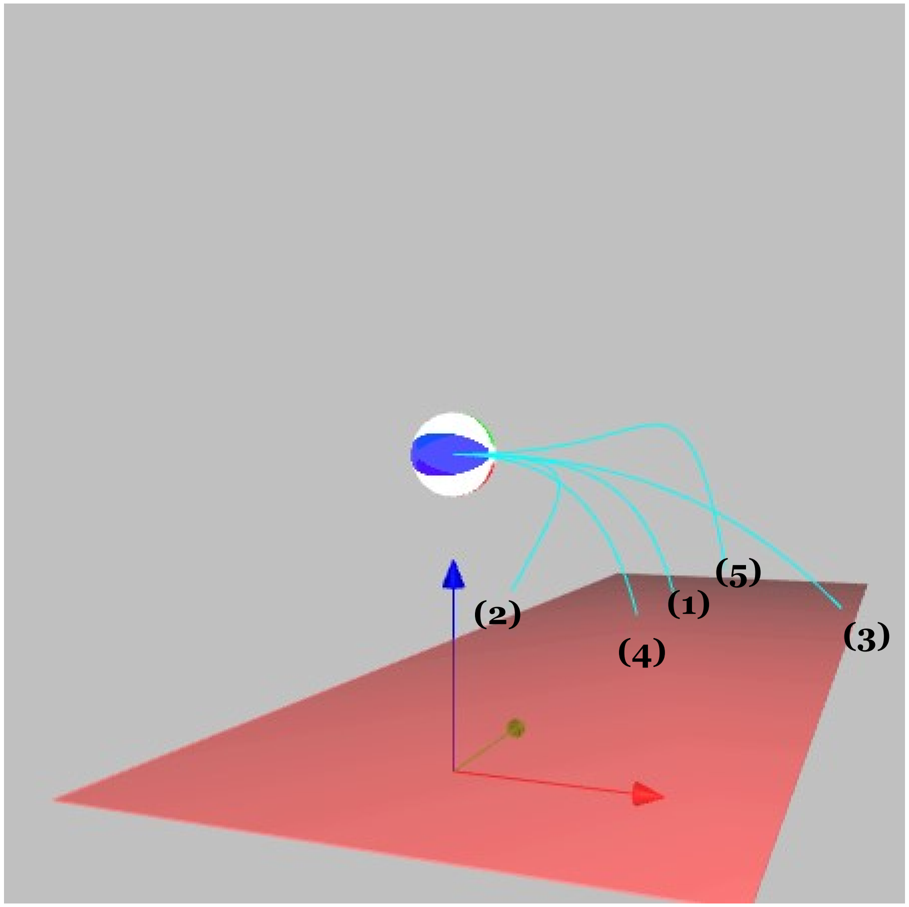
Tracker Snapshots







EJSS Model

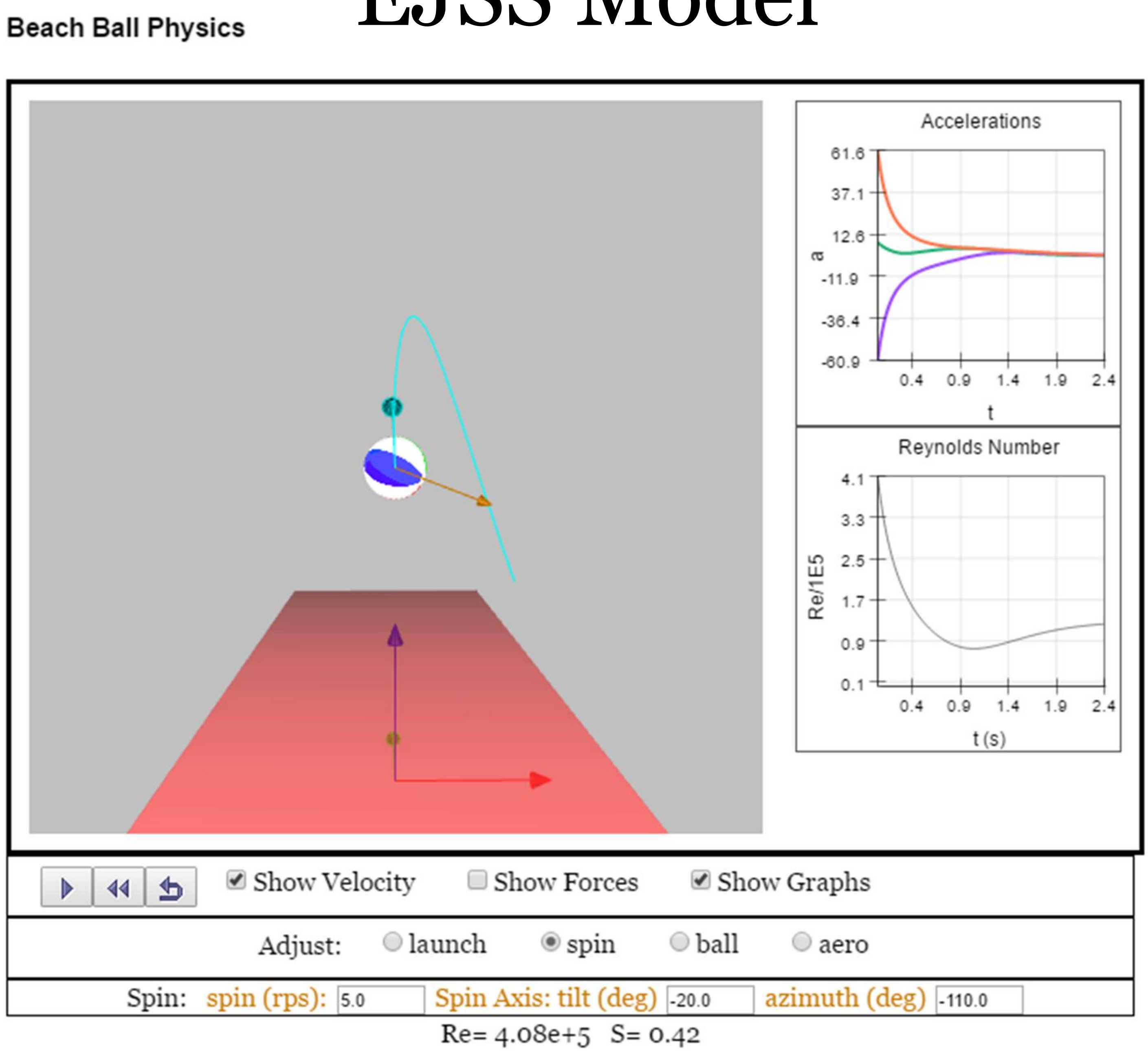


Beach Ball Trajectories:

1) No Spin
2) Curve Left (spin up)
3) Curve Right (spin down)
4) Sinker (top spin)
5) Floater (back spin)

Horizontal launch of medium sized beach ball at 15 m/s from a height of 2 m with a rotation rate of 5 rps.

EJSS Model


Beach Ball Physics
Accelerations
61.6
37.1
12.6
-11.9
-36.4
-60.9
a
0.4
0.9
1.4
1.9
2.4
t
Reynolds Number
4.1
3.3
2.5
1.7
0.9
0.1
Re/1E5
0.4
0.9
1.4
1.9
2.4
t (s)
Show Velocity
Show Forces
Show Graphs
Adjust:
launch
spin
ball
aero
Spin:
spin (rps):
5.0
Spin Axis: tilt (deg)
-20.0
azimuth (deg)
-110.0
Re= 4.08e+5 S= 0.42

Summary

Beach Balls as

- Demonstration Mechanism
  - physical and virtual
- Talking Point
- Experiments into all that pesky "non-ideal" stuff

Simulation (EJSS model)

- Temporary testing grounds:
  - http://phys23p.sl.psu.edu/~mrg3/EJSS/
    - for compiled app, some sources
  - http://phys23p.sl.psu.edu/EJSS/
    - for EJSS tablet app
- Eventually at http://www.opensourcephysics.org/

Additional Thanks:

- Vincent Mitchell, Andrea Solinski
- Baylee Colburn, Kelsey Shaffer