Supporting Information

Schematics of a Water Balloon Launcher Design and Reproducible Water-Balloon-Filling Procedures Used for a Middle School Summer Science Camp

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1.0. Introduction

We recently held a Science Summer Camp for middle school students, designed to infuse young people with increased excitement for STEM (Science, Technology, Engineering, and Math) subjects. Our efforts, which received nationally-syndicated news coverage,[1] included the invention of a versatile water balloon launcher. This document contains: (1) detailed construction schematics and user operation guidelines for our balloon launcher; (2) data and instructions for reproducibly filling water balloons to specific volumes and weights, within <1.5% error; and (3) sample data recording sheets used by students during the summer camp.

2.0. Schematics and Instructions for Building the Launchers

2.1. Launcher Description

Our launcher can hurl water balloons up to 85 meters. It has the educational advantage of enabling students to systematically change the elastic tube length and thereby measure launch results while varying the amplitude. The launch angle can also be analytically set to any number between 0 and 90 degrees (relative to the horizon) as Figures 1A-1C illustrate:

Figures 1A-1C. The launch angle can be systematically varied from 0 (1A) to 45 (1B) to 90 degrees (1C).

2.2. Parts List

Table 2. Parts list.

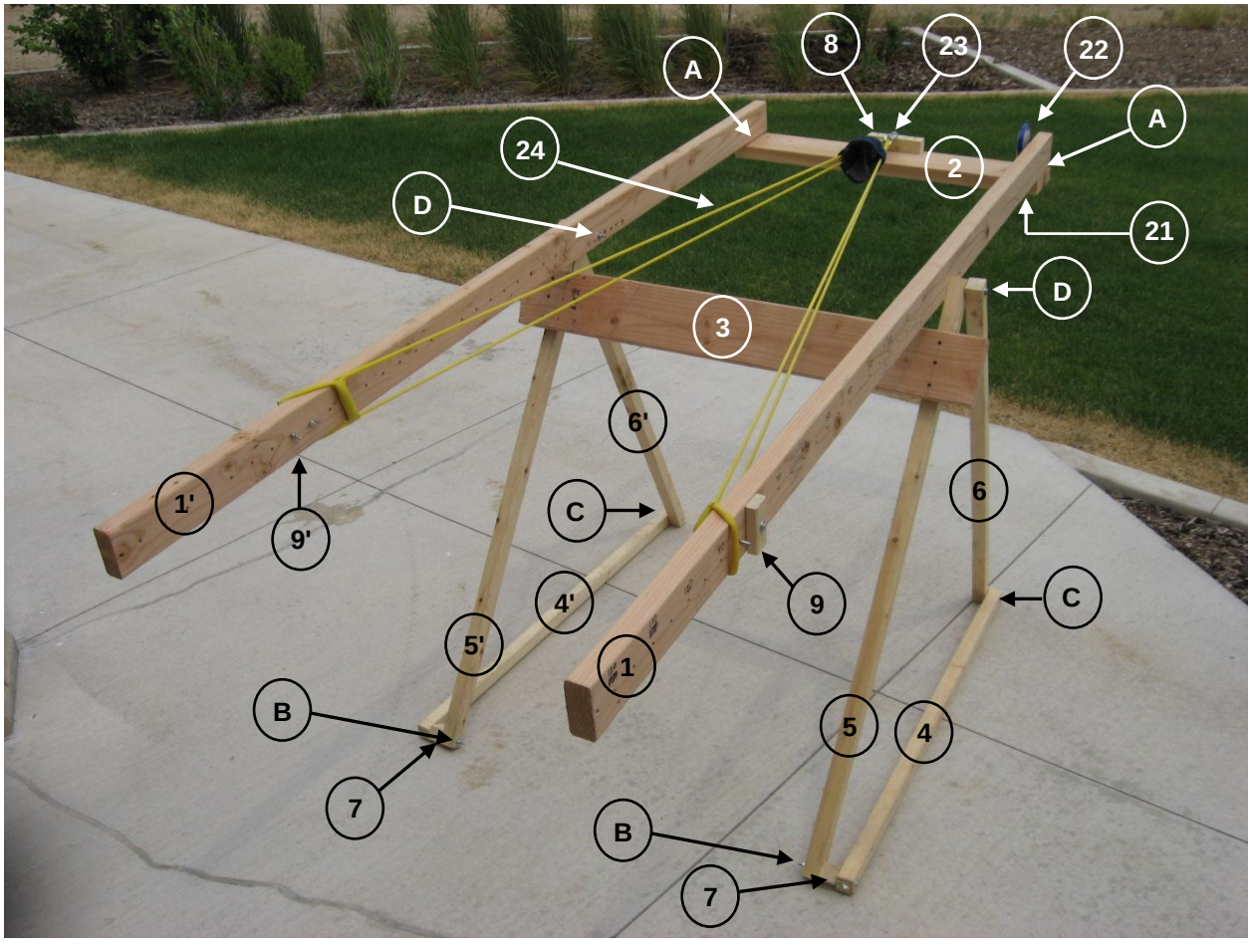
Item(s)	Quantity	Estimated Price	Running Total
Boards			
1. **1, 1'** – 2" x 4" board, 92.5" long	2	$2.40 each/$4.80 total	$4.80
2. **2** – 2" x 6" board, 33" long	1	$3.28 (includes item 3)	$8.08
3. **3** – 2" x 6" board, 42" long	1	Price included in line 2	$8.08
4. **4, 4'** – 2" x 2" board, 49" long	2	$6.68 (includes items 4-8)	$14.76
5. **5, 5'** – 2" x 2" board, 47" long	2	Price included in line 4	$14.76
6. **6, 6'** – 2" x 2" board, 47" long	2	Price included in line 4	$14.76
7. **7** – 2" x 2" board, 1.5" long	2	Price included in line 4	$14.76
8. **8** – 2" x 2" board, 6" long	1	Price included in line 4	$14.76
9. **9, 9'** – 1" x 2" furring strip board, 3" long	2	$0.80 each/$1.60 total	$16.36
Screws and Bolts (not labeled in Fig. 1)			
10. 2.5" fine-thread drywall screws (**10**)	14	$6.92 total	$23.28
11. 0.25" 20 x 3" hex tap bolts, full thread (**11**)	2	$0.58 each/$1.15 total	$24.43
12. 0.25" 20 x 2.5" hex tap bolts, full thread (**12**)	2	$0.52 each/$1.04 total	$25.47
13. 0.25" 20 x 5" hex bolts (**13**)	4	$0.40 each/$1.60 total	$27.07
14. 0.25" 20 x 3.5" hex bolt (**14**)	1	$0.24	$27.31
15. 0.25" 20 x 3" eye bolts (**15**)	2	$1.18 each/$2.36 total	$29.67
Nuts and Washers (not labeled in Fig. 1)			
16. 0.25" 20 nylon lock nuts (**16**)	5	$0.12 each/$0.60 total	$30.27
17. 0.25" 20 x 5/16" tee nuts – pronged (**17**)	4	$3.23 each/$12.92 total	$43.19
18. 0.25" 20 wing nuts (**18**)	6	$0.59 each/$3.54 total	$46.73
19. 0.25" flat washers (**19**)	18	$0.11 each/$1.98 total	$48.71
20. Small screws (**20**)	2	$0.00	$48.71
Other Parts			
21. Metal plate[2] (**21**)	1	$0.00	$48.71
22. Magnetic angle-finder[3] (**22**)	1	$9.86	$58.57
23. 4" fixed-eye panic snap[4] (**23**)	1	$3.99	$62.56
24. Elastic slingshot tubing[5] (**24**)	1	$14.31	$76.87
25. 100 biodegradable water balloons[6]	4 bags	$3.99 each/$15.96 total	$92.83
		Total Cost	**$92.83**

Tools needed: Circular saw, wood glue, drill, 0.25" drill bit, 3/32" drill bit, and two 7/16" wrenches

2.3. Construction Diagram

Figure 2 shows a full construction diagram, to which our assembly instructions below will regularly refer.

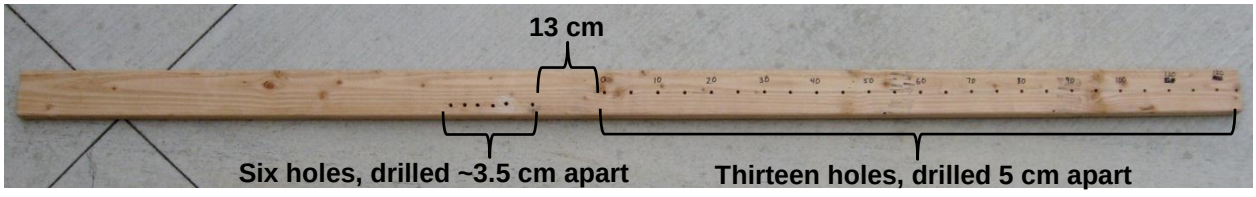
Figure 2. Construction diagram: boards are numbered **1-9**, other parts **21-24**, and Junctures **A-D**.



2.4. Launcher Construction

1. Cut and prepare Boards **1-9** as described in Table 2 above.
2. According to Figure 3 below, drill thirteen horizontal 0.25" holes (spaced 5 cm apart), in succession, along a central line, into boards **1** and **1'**.
3. Beginning 13 cm from the holes drilled in Step 2, add six additional 0.25" holes, spaced apart in 3.5 cm increments. These holes should run in an off-centered horizontal line, about 2.5 cm from the edge of the board (Figure 3).

Figure 3. Boards **1** and **1'**.



4. Secure Board **2** to Boards **1** and **1'** at Junctures **A** (seen in Figures 2 above and 4A-4B below) using three 2.5" fine-thread drywall screws (**10**) per Juncture (six screws total). When making this connection, position the offset holes referred to in Step 3 (drilled into Boards **1** and **1'**) so that they're on the same side as Board **2**, as can be seen in Figure 2.
5. Using two 2.5" fine-thread drywall screws (**10**), secure Board **8** to Board **2** so that Board **8** is facing up and is centered (Figure 4A).
6. Drill a single, centered 0.25" hole through Boards **2** and **8** (Figures 4A-4B).

Figure 4A. Topside view of Board **2**, connected to boards **1** and **1**' at Junctures **A**.

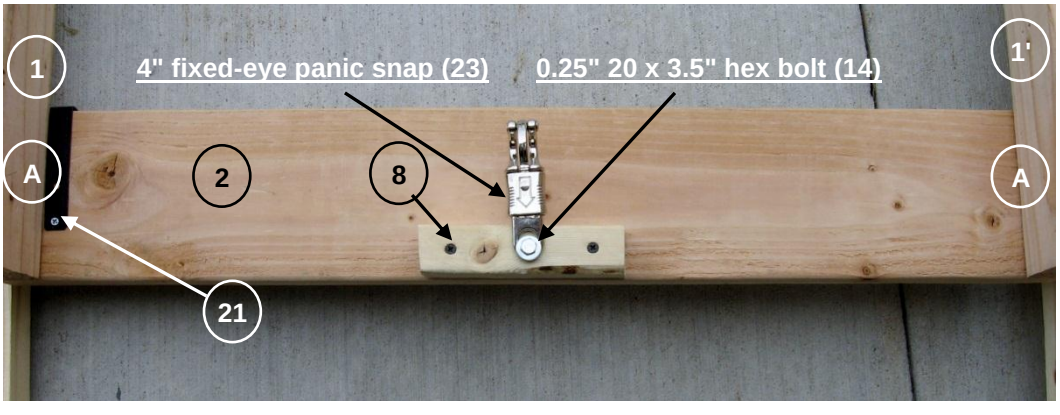
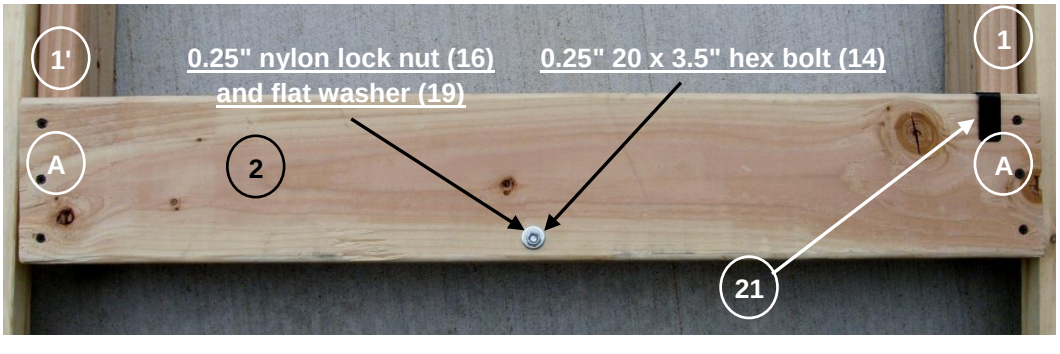


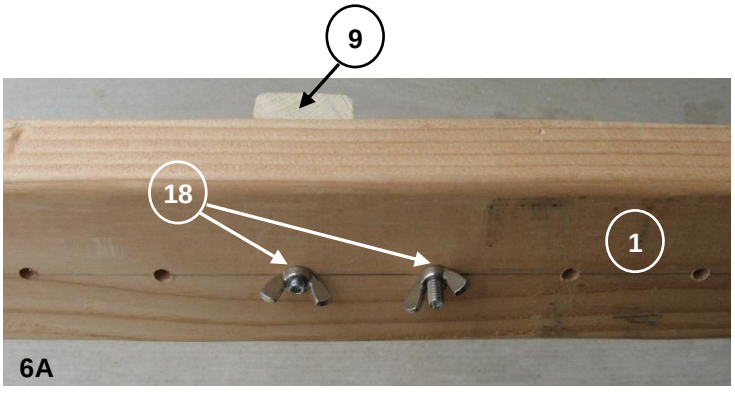
Figure 4B. Underside view of Board **2**, connected to boards **1** and **1**' at Junctures **A**.



7. Using a 0.25" 20 x 3.5" hex bolt (**14**), a 0.25" 20 nylon lock nut (**16**), and a 0.25" flat washer (**19**), secure the 4" fixed-eye panic snap (**23**) to the hole drilled in Step 6 (Figures 4A-4B).
8. Using two small screws (**20**), secure metal plate **21** to Board **2**, according to Figures 4A-4B.
9. According to Figures 2 above and 5-6 below, fasten Board **9** to Board **1** using a 0.25" 20 x 2.5" hex tap bolt (**12**), a 0.25" flat washer (**19**), and a 0.25" 20 wing nut (**18**), placed through one of the holes drilled in Step 2. Repeat for Boards **9'** and **1'**. (Note: it doesn't matter which hole is chosen in this step, since Boards **9** and **9'** are designed to be adjusted. Just be sure that Boards **9** and **9'** are equidistantly positioned from the ends of Boards **1** and **1'**, respectively.)
10. If desired, label the holes drilled in Step 2 as "120, 110, etc.," as seen in Figure 5.
11. According to Figures 2 and 5-6, fasten a 0.25" eye bolt (**15**) through the hole immediately next to Board **9**. Secure **15** using a 0.25" 20 wing nut (**18**). Repeat next to Board **9'**. Note that the location of the eye bolt can be altered by moving it to a different one of the marked holes in Board **1** (Figure 5). This change in position changes the length that the elastic tubing stretches during firing and, hence, the projectiles' exit velocities.

Figure 5. Board **1**, connected to Board **9** and affixed to eye bolt **15**.

Figures 6A-6B. Various angles of the assembly depicted in Figure 5.



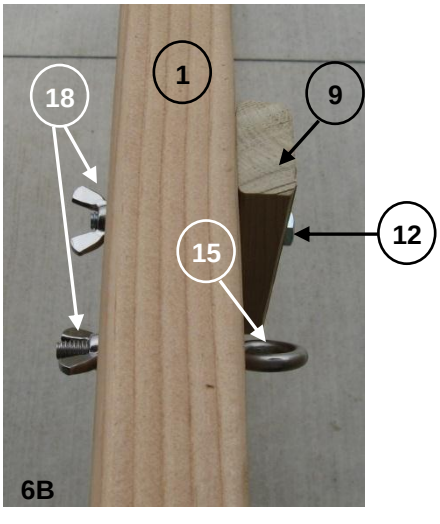
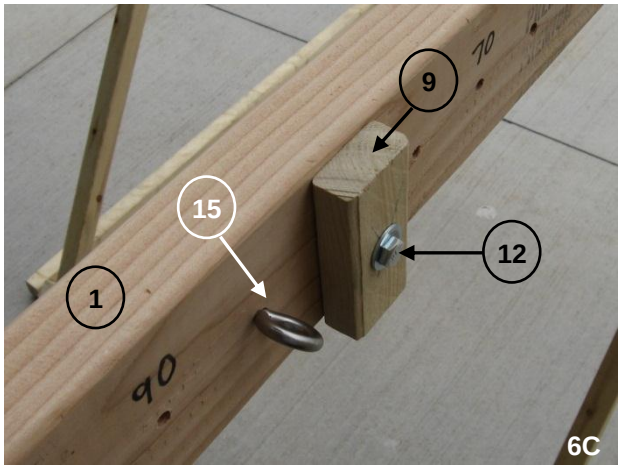
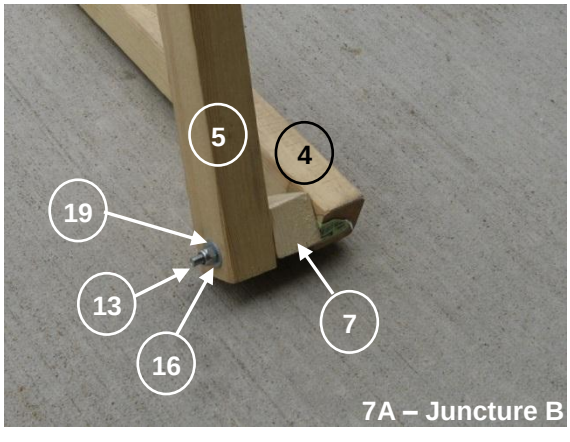


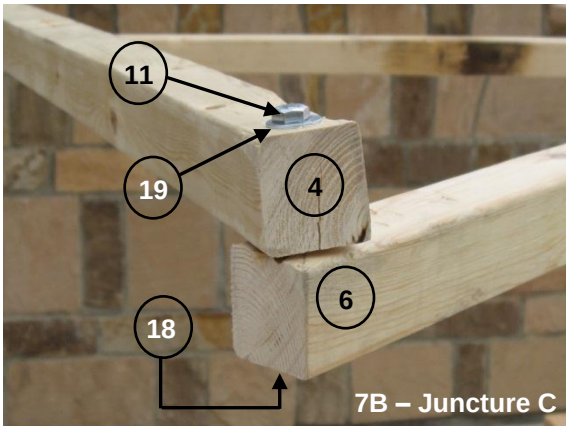
Figure 6C. Additional angle of the assembly depicted in Figure 5.



12. Drill a 0.25" hole through one end of Boards **4**-**5**, and through the centers of Boards **7**. Repeat for Boards **4'**-**5'** (Figure 7A).
13. According to Figure 7A (Juncture **B** in Figure 2), sandwich one Board **7** between Boards **4** and **5** using a 0.25" 20 x 5" hex bolt (**13**), a 0.25" flat washer (**19**), and a 0.25" 20 nylon lock nut (**16**). Repeat for a second Board **7** and Boards **4'**-**5'**.
14. According to Figure 7B (Junctures **C** in Figure 2), drill a 0.25" hole through the remaining end of Board **4** and through one end of Board **6**. Repeat for Boards **4'** and **6'**.
15. According to Figure 7B, secure Board **4** and **6** using a 0.25" 20 x 3" hex tap bolt (**11**), a 0.25" flat washer (**19**), and a 0.25" 20 wing nut (**18**). Repeat for Boards **4'** and **6'**.

Figures 7A-7B. Sandwich Junctures **B** [Boards **4**, **5**, and **7** (7A)] and **C** [Boards **4** and **6** (7B)].

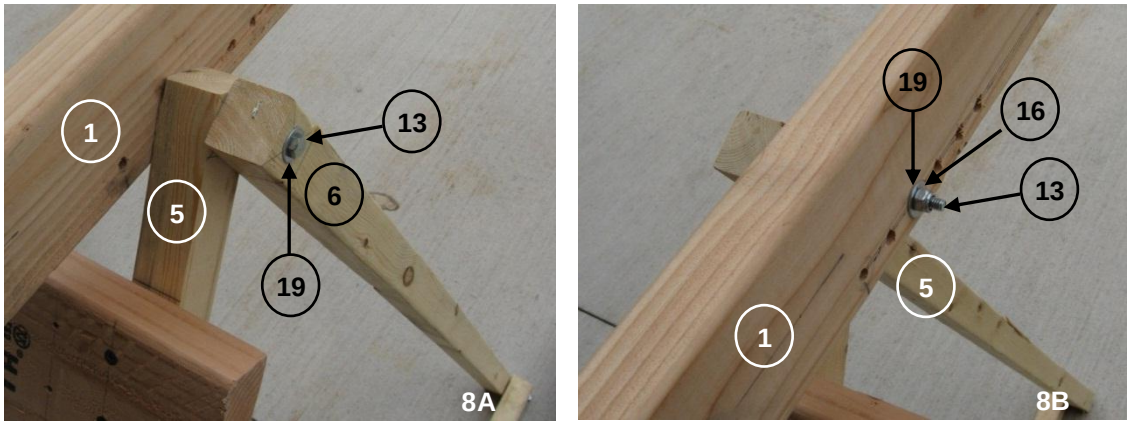




16. Drill a 0.25" hole through the top ends of Boards **5**-**6** (Junctures **D**, Figures 8A-8B). Repeat for Boards **5'**-**6'**.

17. Assemble Junctures **D** (shown in Figures 2 and 8A-8B) by securing Boards **5**-**6** to Board **1** using a 0.25" 20 x 5" hex bolt (**13**), a 0.25" flat washer (**19**), and a 0.25" 20 nylon lock nut (**16**). (Note: it doesn't matter which hole in **1** is chosen in this step, since Junctures **D** are designed to be adjusted.) Repeat for Boards **5'**, **6'**, and **1'**.

Figures 8A-8B. Inner and outer views of Junctures **D**.



18. Secure Board **3** to Boards **5** and **5'** using three 2.5" fine-thread drywall screws (**10**) per side (six screws total, Figure 9).
19. The completed triangular stand assembly should now look like Figure 10 below.
20. Position the magnetic angle-finder[3] (**22**) onto metal plate **21**, according to Figure 11.

Figure 9. Attachment of Board **3** to Boards **5** and **5'**.

Figure 10. Completed triangular stand assembly.

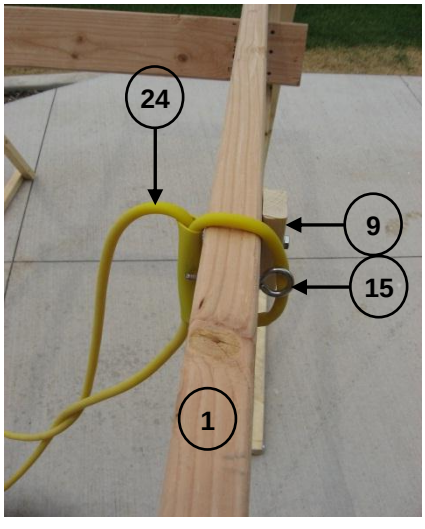
Figure 11. Positioning the magnetic angle-finder (**22**) onto metal plate **21**.

3.0. Launcher Operation

1. Before operating the launcher, each looped end of the elastic slingshot tubing (**24**) should be secured between Boards **9** and **9'** and eye-bolts **15**, according to Figure 12 below. As was Step 9 indicated above, the position of Boards **9** and **9'** can be adjusted in concert with **15**, down the length of Board **1** and **1'**, to alter the launching amplitude.
2. Take proper safety precautions:
    a. Ensure that no one is standing in or near the firing range (the front of the launcher), as impact with the elastic tubing or a sailing balloon may cause serious injury.

b. All operators and individuals nearby (within 15 feet of the launcher) should wear proper eye protection to avoid injury.

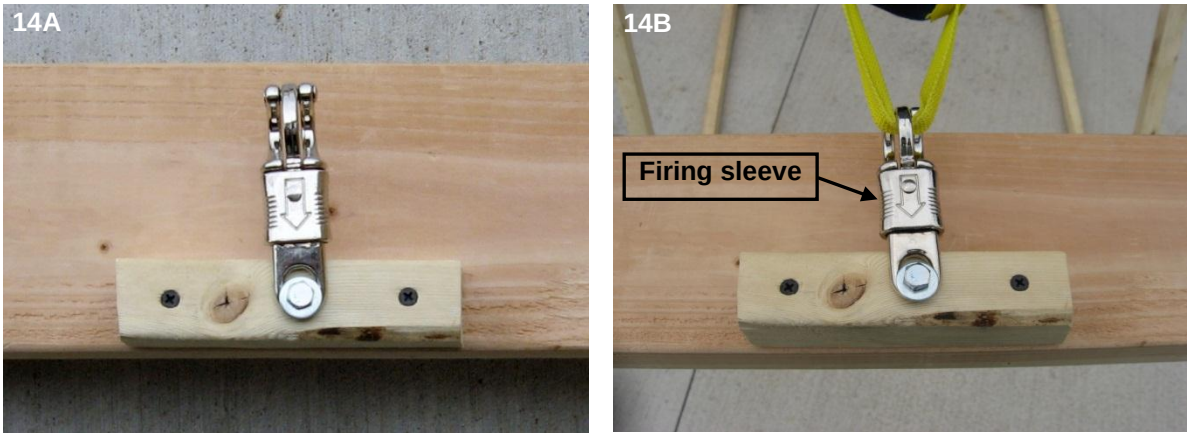
Figure 12. Elastic slingshot tubing positioning.



3. Stretch the elastic slingshot tubing[6] into its fully drawn position (Figure 13) and lock it into the panic snap (Figures 14A-14B). (Note: Do not stretch the tubing more than eight feet.)

Figure 13. Elastic tubing shown fully drawn.

Figures 14A-14B. Panic snap shown empty (14A) and with the elastic slingshot secured (14B).

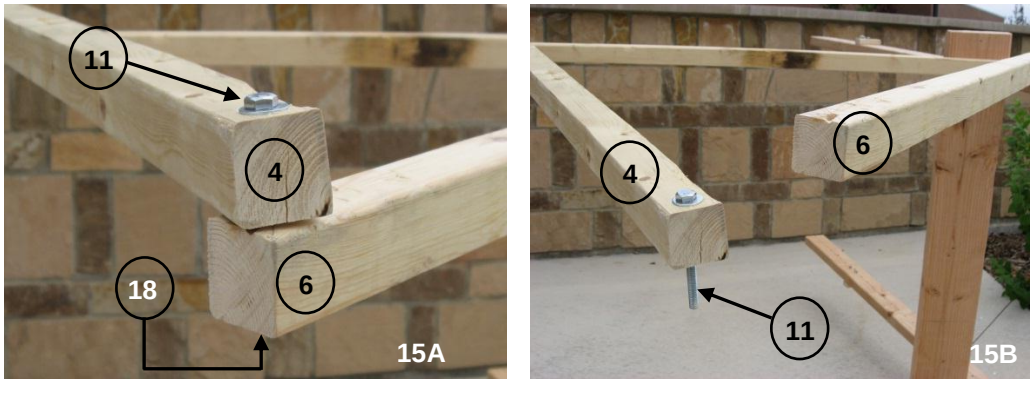


4. Load a water balloon into the slingshot.
5. Pull back on the panic snap's firing sleeve (labeled in Figure 14B) to release the elastic tubing and fire the balloon.

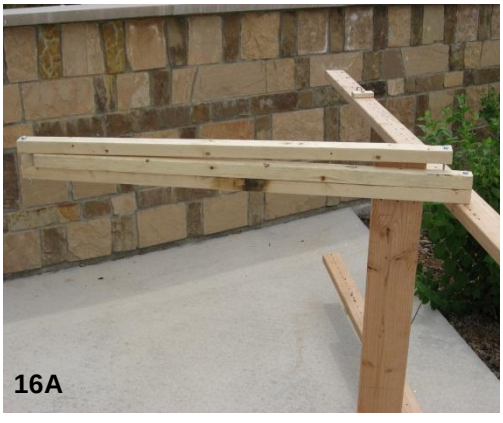
4.0. Folding the Launcher for Travel and Storage

1. The launcher is designed to fold up for easier storage or travel, as follows:
    a. At Junctures **C**, remove the 0.25" 20 wing nut (**18**) and then pull bolt **11** out of Board **6**, separating Boards **4** from **6** (Figures 15A-15B).
    b. Fold Boards **4** and **6** into the configuration shown in Figure 16A.
    c. Repeat steps a-b for Boards **4'** and **6'**. The launcher can now be laid flat, as Figure 16B illustrates.

Figures 15A-15B. Boards **4** and **6** (Junctures **C**) are separated to allow the launcher to be folded up.



Figures 16A-16B. Boards **4** and **6** (Junctures **C**) are separated and collapsed (16A) to allow the launcher to be folded up (16B).



5.0. Water Balloon Preparation

5.1. Filling Water Balloons to a Consistent Mass

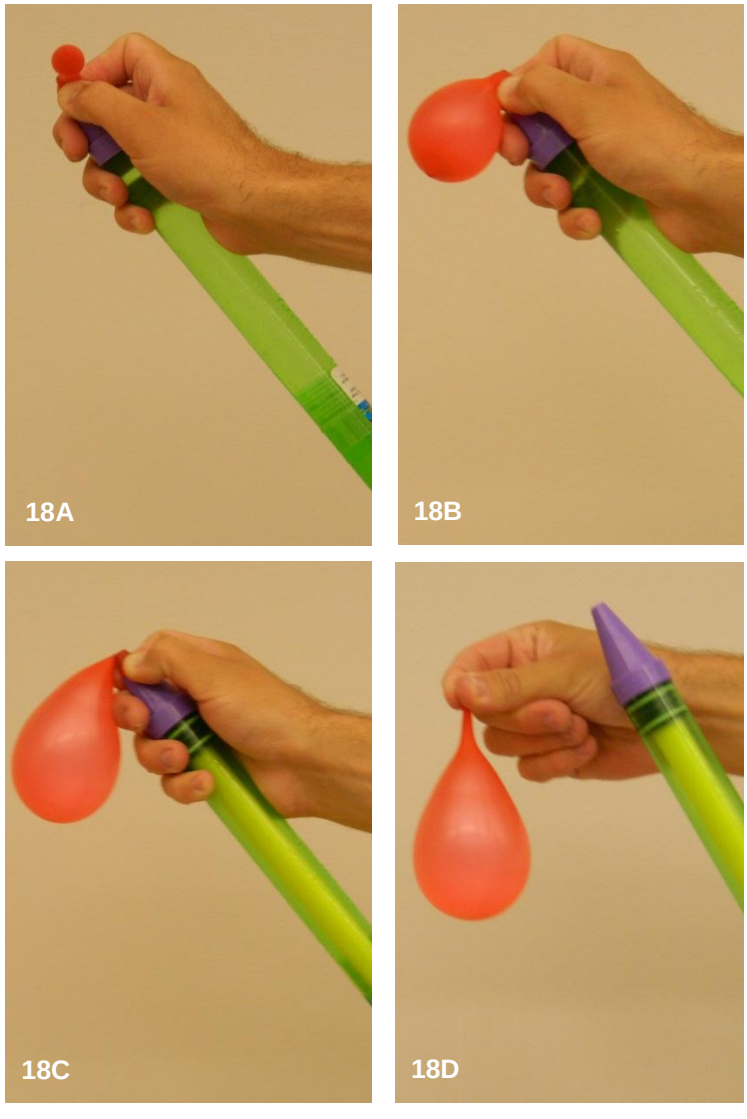
For student groups who measured the effects of systematically altering amplitude and launch angle, consistent balloon masses were required. Over 120 balloons were filled to consistent masses, as follows:

1. An "H_2O blasters" 26-inch water blaster tube[7] was filled with about 185 mL of water. (Note: the exact volume used is not as important as maintaining consistency; thus, the volume may be varied here, depending on the size of balloons used.)
2. The 185 mL water level was marked on the sides of the blaster tube, using permanent marker (Figure 17A).
3. The water tube's nozzle was submerged in a plastic dish tub filled with water.
4. The water tube's plunger was slowly drawn up, filling the tube with water to the 185 mL mark (Figure 17B).

Figures 17A-17B. The water blast tube, with its 185 mL water level marked (17A) and filled with water to the mark (17B).

5. With one hand on the tube's nozzle and another on its plunger, a water balloon[6] was carefully secured to the end of now-filled water tube (Figure 18A below).
6. The tube's plunger was then compressed to expel its 185 mL volume into the balloon (Figures 18B-18D below).
7. The balloon was carefully tied and weighed.

Figures 18A-18D. Filling the water balloon with the water blaster tube.



A second 26-inch water blaster tube was marked to the same level by using the first tube as a calibrator. Two undergraduates then filled over 120 balloons in about five hours. Sixty of these, filled using *both* blaster tubes and chosen at random, were weighed with an analytical balance and gave the results seen in Table 3 below. Their average weight was 184.646 grams. The % deviation of each balloon (1 through 60) from the average is shown in each entry. The average % deviation for all 60 balloons was 0.42%. Once filled, balloons were stored overnight, being submerged underwater in a large plastic bucket, prior to use.

Table 3. Weights and % deviations from the average of water balloons 1-60, filled according to Steps 5.1.

Balloon	Weight (g)	% deviation	Balloon	Weight (g)	% deviation
1	185.6	0.52%	**31**	184.7	0.03%
2	184.6	0.02%	**32**	182.9	0.95%
3	185.5	0.46%	**33**	184.8	0.08%
4	185.2	0.30%	**34**	185	0.19%
5	186.1	0.79%	**35**	182	1.43%
6	185.4	0.41%	**36**	186.4	0.95%
7	185.2	0.30%	**37**	184.3	0.19%
8	184.8	0.08%	**38**	185	0.19%
9	186	0.73%	**39**	184.2	0.24%
10	184.6	0.02%	**40**	184.3	0.19%
11	184.7	0.03%	**41**	183.4	0.67%
12	185.4	0.41%	**42**	183.2	0.78%
13	184.6	0.02%	**43**	183.8	0.46%
14	185.3	0.35%	**44**	185	0.19%
15	185.7	0.57%	**45**	183.9	0.40%
16	184.5	0.08%	**46**	184.6	0.02%
17	184.4	0.13%	**47**	184.7	0.03%
18	184	0.35%	**48**	182.8	1.00%
19	185.8	0.63%	**49**	184.8	0.08%
20	185.9	0.68%	**50**	183.3	0.73%
21	186	0.73%	**51**	184.8	0.08%
22	183.8	0.46%	**52**	186.4	0.95%
23	180.6	2.19%	**53**	183.9	0.40%
24	185.5	0.46%	**54**	185.4	0.41%
25	185.3	0.35%	**55**	184.8	0.08%
26	185.1	0.25%	**56**	183.3	0.73%
27	184.9	0.14%	**57**	183.8	0.46%
28	184.1	0.30%	**58**	184.8	0.08%
29	185.4	0.41%	**59**	184.1	0.30%
30	185.7	0.57%	**60**	184.7	0.03%
Average weight (g)		**184.646**	**Average % deviation**		**0.42%**

5.2. Preparing Water Balloons of Varied Masses

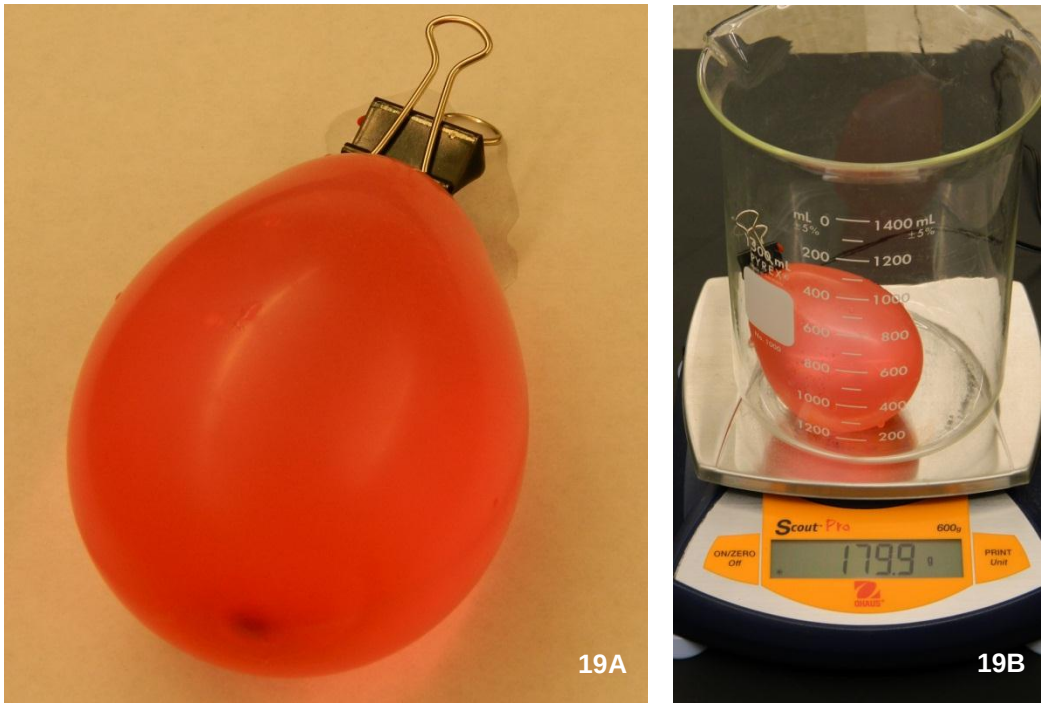
For student groups who measured the effects of systematically *altering* balloon masses, 56 balloons were filled, having the following masses: 90 grams (eight balloons), 180 grams (eight balloons), 270

grams (eight balloons), 360 grams (eight balloons), 450 grams (eight balloons), 540 grams (eight balloons), and 630 grams (eight balloons). This was accomplished as follows:

1. Using an "H_2O blasters" 26-inch water blaster tube,[7] a water balloon[6] was filled with a volume of water that looked (by human judgment) to be near the target weight (either 90 grams, 180 grams, 270, grams, 360 grams, 450 grams, 540 grams, or 630 grams).
2. A small, office binder clip was used to clip the mouth of the balloon shut (Figure 19A).
3. The balloon was weighed on a 600-gram analytical balance by placing it inside a 1500 mL beaker that was positioned and zeroed on the balance beforehand (Figure 19B).
4. Depending on the weight measured, water was either removed or added to reach the target mass.
5. Once the target mass was achieved, the balloon was carefully tied.

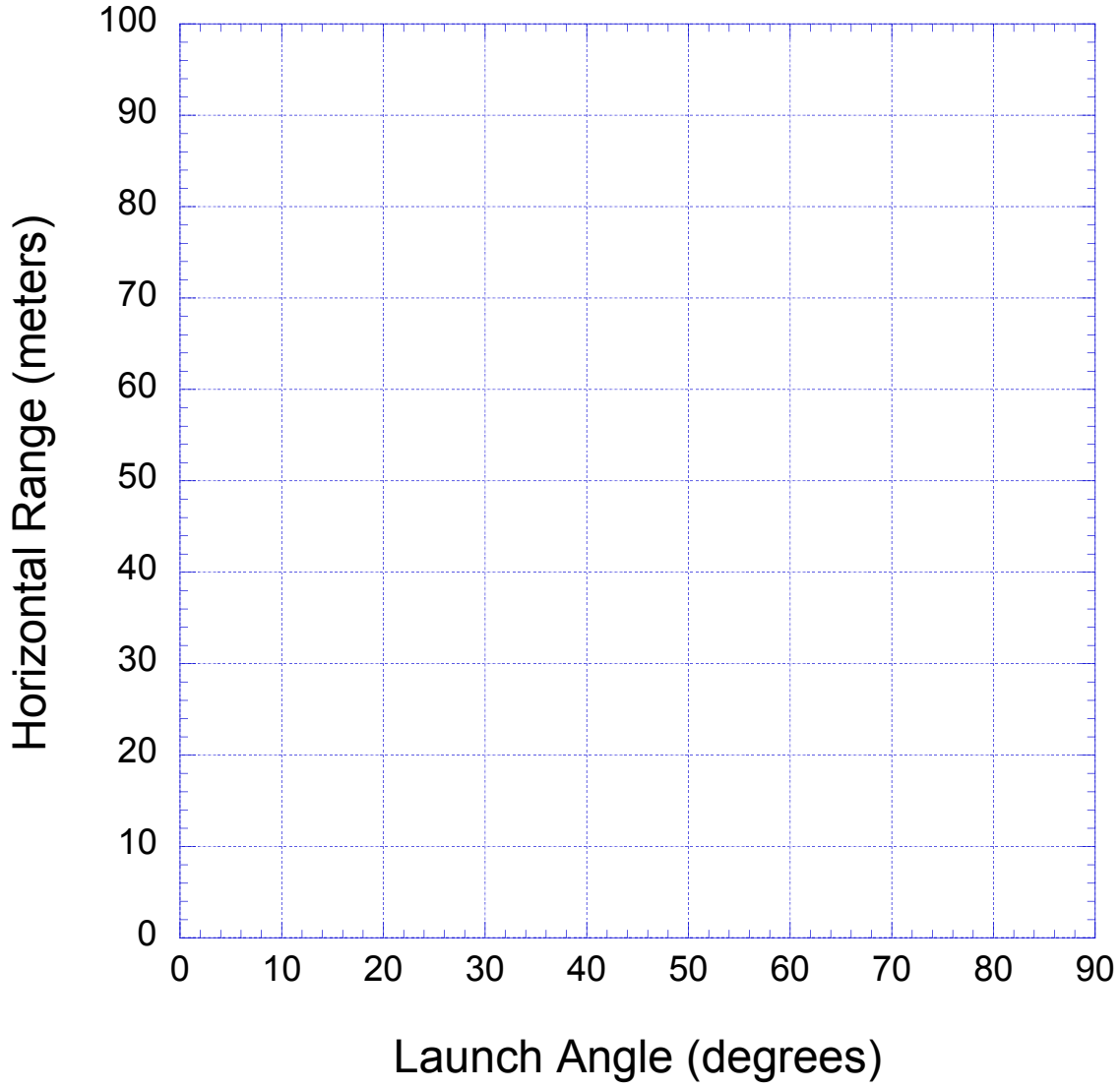
It was common for some of the balloons to burst prior to use, particularly the heavier-volume ones. Thus, it is best to prepare extras.

Figures 19A-19B. Securing a filled water balloon with an office binder clip (19A), and weighing it on an analytical balance (19B). A ~180-gram balloon is shown.



Team Name	
1. Captain	
2. Loader	
3. Launcher	
4. Measurer	
5. Recorder	
Initial Displacement (centimeters)	
Balloon Volume (milliliters)	

Launch Angle (degrees)	Horizontal Range (meters)
0	
15	
30	
45	
60	
75	
90	



Team Name	The angles ? the saxons
1. Captain	Erik (INCHARGE)
2. Loader	Toby (Pull it Back)
3. Launcher	Preston (and go!)
4. Measurer	Mckenna (USE THAT YARD STICK!)
5. Recorder	Heidi I JUST WRITE
Initial Displacement (centimeters)	
Balloon Volume (milliliters)	

Launch Angle (degrees)	Horizontal Range (meters)
0° It Gette Better	16 meters
15° Better till it's	35 meters
30° absolutly	61 meters
45° AWSOME!!	65½ meters
60° Then It gets	55¾ meters
75° worse practically	20½ meters
90° HEADS TO LANDSONOUR	7 meters

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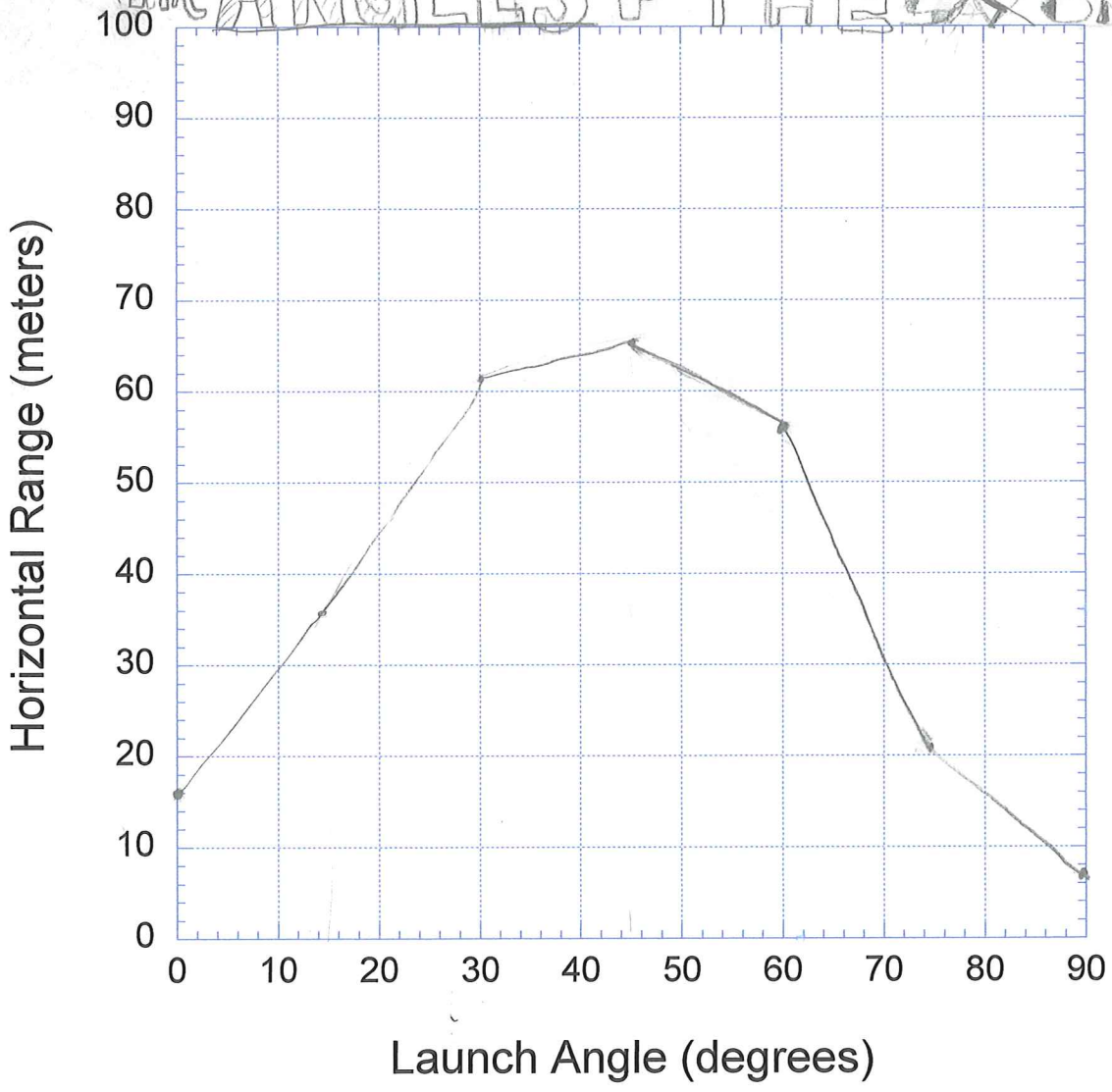
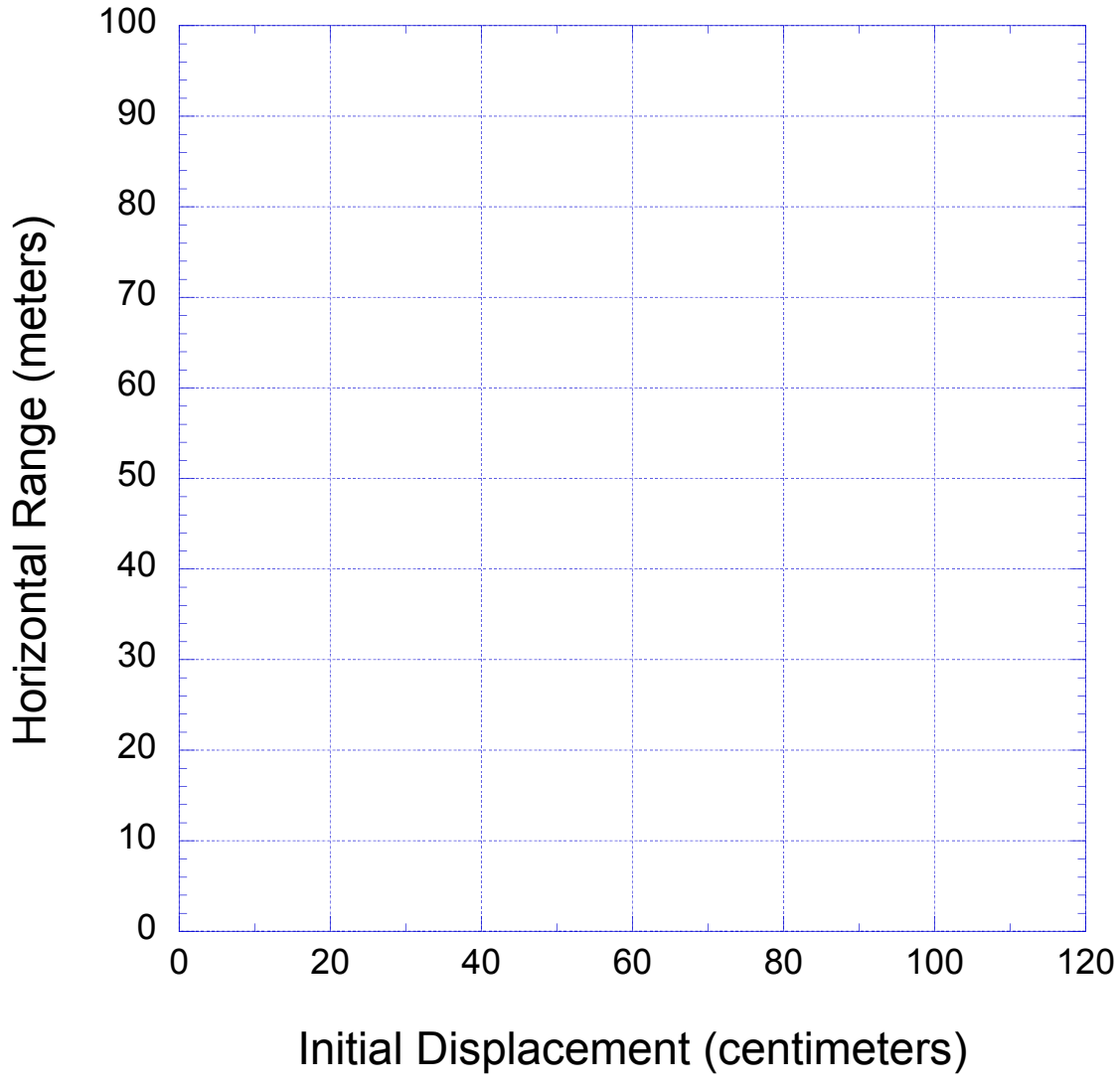
The ANGLES ? THE SAXONS



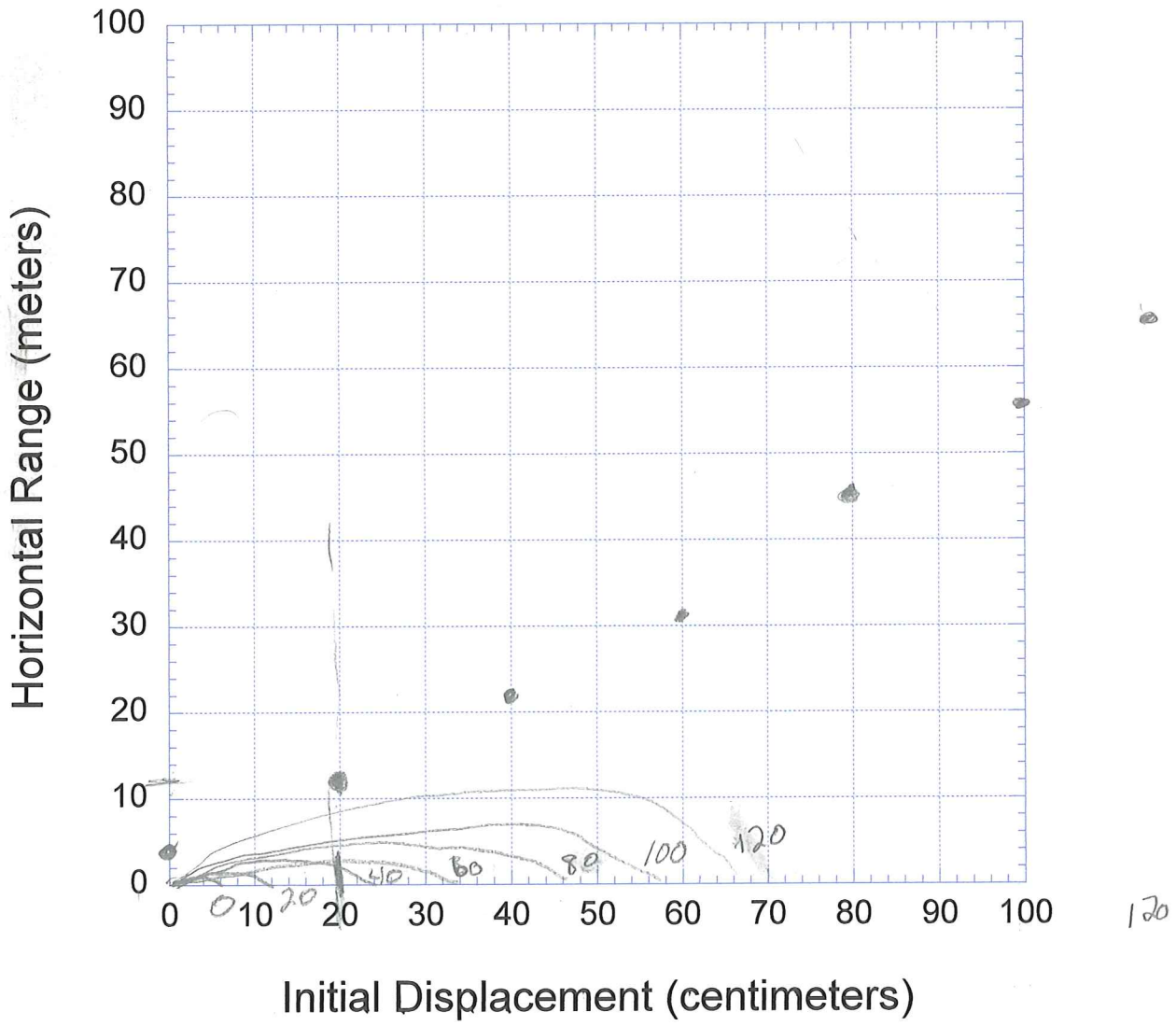
Team Name	
1. Captain	
2. Loader	
3. Launcher	
4. Measurer	
5. Recorder	
Launch Angle (degrees)	
Balloon Volume (milliliters)	

Initial Displacement (centimeters)	Horizontal Range (meters)
0	
20	
40	
60	
80	
100	
120	



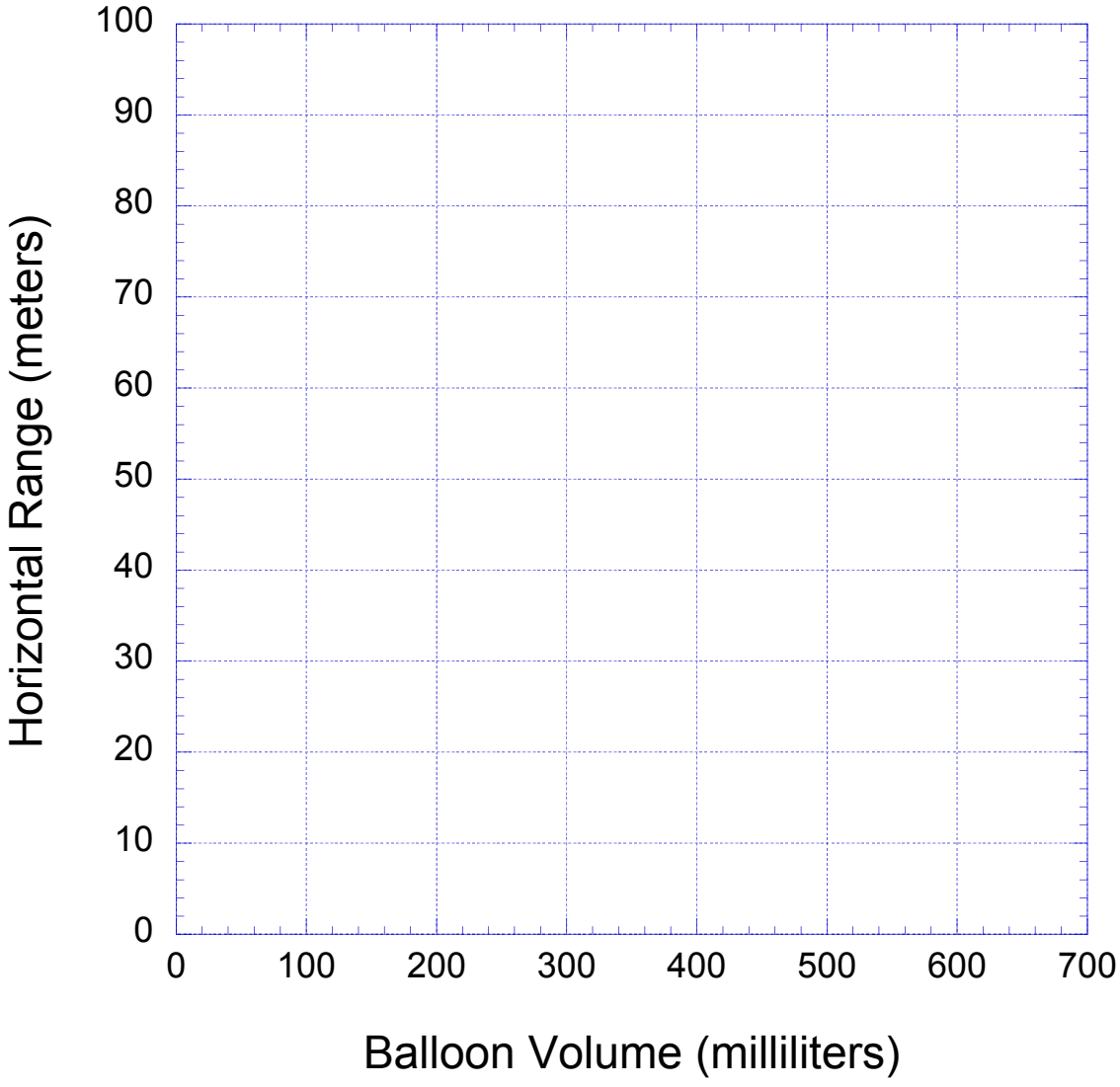
Team Name	
1. Captain	Alysa
2. Loader	Daniel
3. Launcher	Gabe
4. Measurer	SCOTTY
5. Recorder	Trevor
Launch Angle (degrees)	30°
Balloon Volume (milliliters)	

Initial Displacement (centimeters)	Horizontal Range (meters)
0	4
20	11.5
40	22
60	33
80	46
100	55
120	66



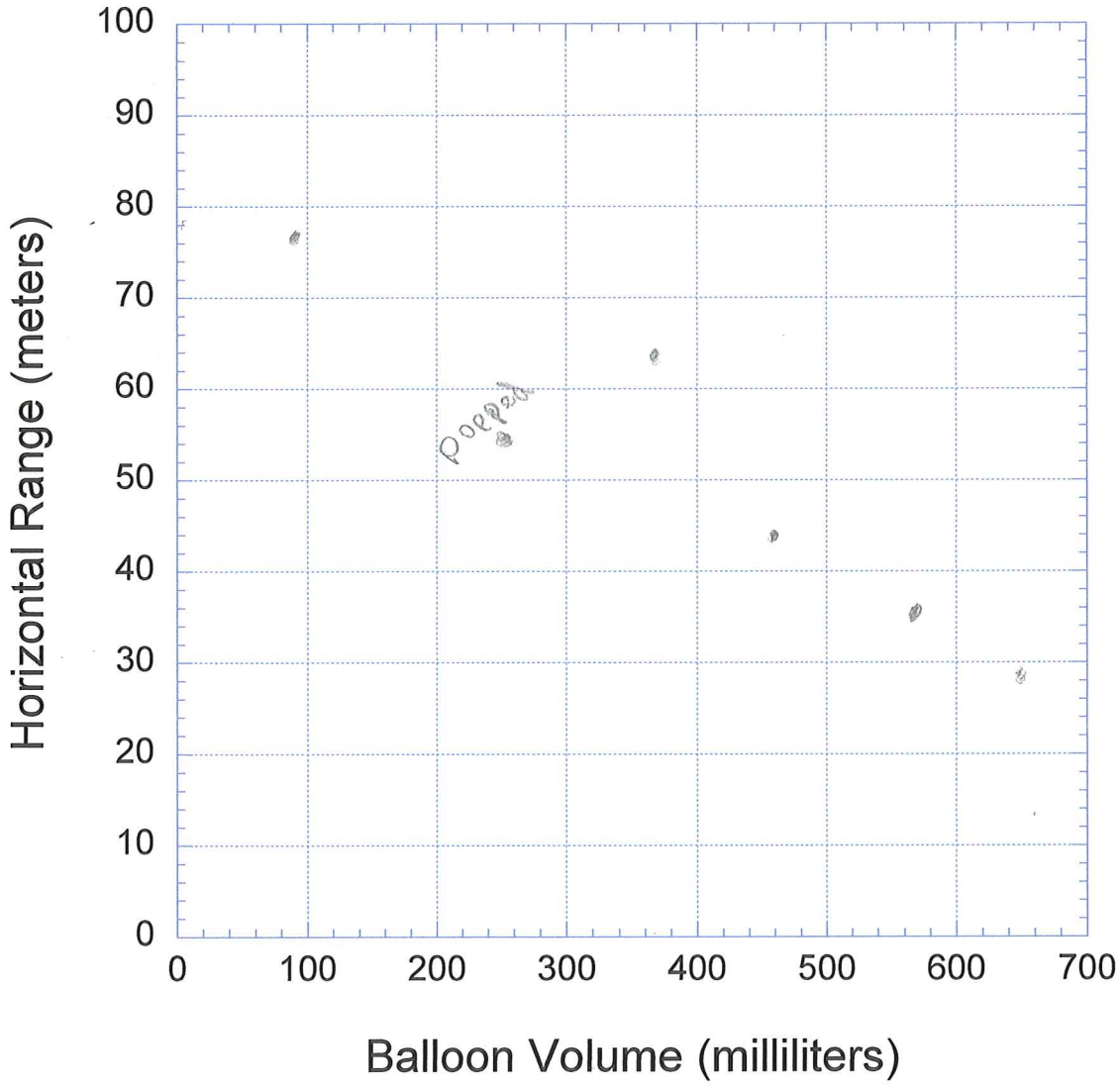
Team Name	
1. Captain	
2. Loader	
3. Launcher	
4. Measurer	
5. Recorder	
Launch Angle (degrees)	
Initial Displacement (centimeters)	

Balloon Volume (milliliters)	Horizontal Range (meters)
90	
180	
270	
360	
450	
540	
630	



Team Name	
1. Captain	Tyler
2. Loader	Russel
3. Launcher	Jaina
4. Measurer	Trinity
5. Recorder	
Launch Angle (degrees)	
Initial Displacement (centimeters)	

Balloon Volume (milliliters)	Horizontal Range (meters)
90	79
180	74 *popped
270	55 *popped
360	65
450	43½
540	37
630	33½



7.0. References and Notes

1. For news coverage of the event, see: (a) Liesik, G. USU camp teaches kids the science of Angry Birds. *Deseret News,* June 1, 2012. (b) Liesik, G. Kids learn science of Angry Birds at USU camp. *KSL News.* [Online] **2012.** http://www.ksl.com/?nid=960&sid=20662672&title=kids-learn-science-of-angry-birds-at-usu-camp&s_cid=queue-11 (accessed June 26, 2012).
2. "Sunwood Glazing Support Bracket," available from http://supplies.trulypvc.com/ (accessed Jul 12, 2013).
3. "Swanson Tool Company Magnetic Angle Finder," available at Lowe's (item #198122).
4. "High-Grade 4" Fixed-Eye Panic Snap Non-Rust Zinc," available on Amazon.com.
5. "CX Blaster Water Balloon Launcher - 200 Yard," available on Amazon.com.
6. "Biodegradable Water Balloons 100 pack," available on Amazon.com
7. "H_2O blasters" 26-inch water blaster tubes. Manufactured by Greenbrier International, Inc. and distributed by Dollar Tree. Accessible online at http://www.dollartree.com/Water-Blaster-Tubes-26-/p307984/index.pro (accessed July 12, 2013).
8. Related literature and balloon launcher designs from other institutions can be consulted and compared at the following references: (a) J. Pantaleone and J. Messer. The added mass of a spherical projectile. *Am. J. Phys.* 79 (12), **December 2011**: 1202-1210. (b) R. A. Bachman. Idealized dynamics of balloon flight. *Am. J. Phys.* 52 (4), **April 1984**: 309-312. (c) Rod Cross. Aerodynamics in the classroom and at the ball park. *Am. J. Phys.* 80 (4), **April 2012**: 289-297. (c) Read, G. An application of elementary calculus to balloons. *Eur. J. Phys.* 7, **1986**: 236-241. (d) Akiyama, H.; Nishimura, J.; Namiki, M.; Okabe, Y.; Matsuzaka, Y.; Hirosawa, H. A new Static-launch method for plastic balloons. *3*, **1983**: 97-100. (e) Yamagami, T.; Saito, Y.; Matsuzaka, Y.; Namiki, M.; Toriumi, M.; Yokota, R.; Hirosawa, H.; Matsushima, K. Development of the highest altitude balloon. *Advances in Space Research,* Vol. 33, **2004**: 1653-1659. (f) Engineering Design: Design Sequence Webpage (Trinity University), http://web.trinity.edu/x7494.xml (accessed Jul 12, 2013). (g) Balloon Launcher Project Homepage, http://www.resnet.trinity.edu/cbauer/page%204.htm (accessed Jul 12, 2013). (h) Water Balloon Launcher, by tinnustechnology Webpage, http://www.instructables.com/id/Water-Balloon-Launcher/ (accessed Jul 12, 2013). (i) Balloon Bazooka: the Ultimate Water Balloon Launcher, product homepage, http://balloonbazooka.com/product_details.html (accessed Jul 12, 2013).