CAT 1 : EXTENDED PRATICAL INVESTIGATION

THE BEHAVIOUR OF PROJECTILES

Table of Contents

Abstract

This investigation aimed to analyse the behaviour of projectiles, considering departure angles, velocities and points of measurement.

An increase in velocity led to further vertical and horizontal displacements due to a greater force of energy and the projectile's maximum horizontal and vertical displacements occured at 45° due to both the horizontal and vertical velocities of the projectile being equal. When comparing experimental against theoretical values, the experimental data was either the same or below the theoretical values. This discrepancy was accredited to both friction and adhesive forces as the water travelled down the tube and to air resistance as it travelled through the air. Thus, the friction occuring between the tube and the water produced a greater net drag force, decreasing the theoretical velocity calculated, in turn reducing the maximum possible displacements.

Investigating different points of measurements for each chosen angle, the horizontal displacements increased as the distance from the point of the nozzle vertically downwards increased. It was also concluded that when varying the angle the horizontal displacement of the projectile decreased as the departure angle increased at all distances below the 0 cm reference point, due to a longer flight time.

Introduction

The purpose of this project was to analyse and evaluate the behaviour and motion of projectiles under varying conditions. To simulate a projectile a constant velocity water jet was used. Experiment 1 made comparisons between experimental and theoretical measurements of vertical and horizontal displacement of the water jet at a constant velocity and varying departure angles. Benoulli's equation relates constant velocity to the distance between the nozzle and level of water in the bottle thus;

$$V_o = \sqrt{2g.H_A}$$ [1]

where V_o = departure velocity
H_A = distance between water level and nozzle
$g = 9.8\ ms^{-2}$

Using this value theoretical displacements were calculated.

vertical displacement $= \dfrac{(V_o^2 . \sin^2\theta)}{2g}$

horizontal displacement $= \dfrac{(V_o^2 . \sin 2\theta)}{g}$

where θ = departure angle

Experiment 2 compared the behaviour of projectile using a higher constant velocity than in experiment 1. This provided confirmation of the conclusions drawn in experiment 1 comparing experimental and theoretical values.

Using the conclusions drawn from experiments 1 and 2 regarding maximum horizontal displacement, experiment 3 looked at maximising this horizontal displacement given an upper limit to departure velocity.

Variables

Angles
In experiment 1 and 2 angles were varied from 0° to 90°, in increments of 5°, at constant velocities. Using a spirit level attached to the nozzle enabled conclusions to be formed concerning the effect the departure angle has on the behaviour of a projectile.

Velocity
The velocity of the projectile is directly related to the height of the water above the nozzle point[2]. It was found that increased height produced an increased velocity; decreased height distance produced a decreased velocity. Through varying the velocity, the effect on the projectile was investigated.

[1] Halliday, D and Resnick, R *Fundamentals of Physics* 3rd Ed. John Wiley and Sons USA 1988
[2] Benoulli's Equation

Measuring distances below the horizontal

Experiment 3 involved varying the vertical distance below the nozzle at which the horizontal displacement was measured. This enabled conclusions on maximising horizontal displacement under fixed velocity.

All attempts were made to keep the environmental conditions constant, including temperature and air velocity. This was done by closing all windows and doors into the experiment room and minimising movement in the room whilst taking measurements.

Difficulties

When beginning the experiment the apparatus leaked, leading to inconsistent findings. This problem was solved by super-gluing the equipment involved in the transporting of water.

Due to the unavailability of sophisticated equipment it was very difficult to maintain the level of water in the bottle at a constant height, resulting in a varying velocity. To minimise this inaccuracy, one person kept the level relatively constant by controlling the rate of flow of the water from the tap.

When varying the velocity, it was found that as the water bottle was moved up the retort stand the apparatus became unbalanced causing variability in the flow of water. The problem was overcome by tying the retort stand to the wall, thus holding the apparatus vertical.

Measuring the maximum displacement, vertically and horizontally proved difficult at the extremities of departure angles. When measuring vertical displacement for a departure angle 90° the projectile fluctuated significantly, thus a average measurement was taken.

Background Theory

The aim in experiments 1 and 2 was to investigate Benoulli's equation by calculating velocity then drawing conclusions based on theoretical and experimental values of displacement.

$$P_A + D_A g H_A + 1/2.D_A V_A^2 = P_B + D_B g H_B + 1/2.D_B V_B^2$$

where P = pressure
D = density
H = distance between water level and nozzle
V = velocity
g = 9.8ms^{-2}

Assuming constant pressure, density and velocity an equation was derived from Benoulli's equation relating velocity and height of water.

$$\therefore D_A g H_A + 1/2.D_A V_A^2 = D_B g H_B + 1/2.D_B V_B^2$$

$$\therefore D_A(gH_A + 1/2.V_A^2) = D_B(gH_B + 1/2.V_B^2)$$

$$\therefore 2g.H_A + V_A^2 = 2g.H_B + V_B^2$$

$$\text{as } V_A = V_B$$

$$\therefore V_o^2 = 2g.H_A$$

$$\therefore \mathbf{V_o = \sqrt{2g.H_A}}$$

N.b. see article for derivation of vertical and horizontal displacement equations.

Experimental Procedure

The apparatus was set up show in figure 1.1

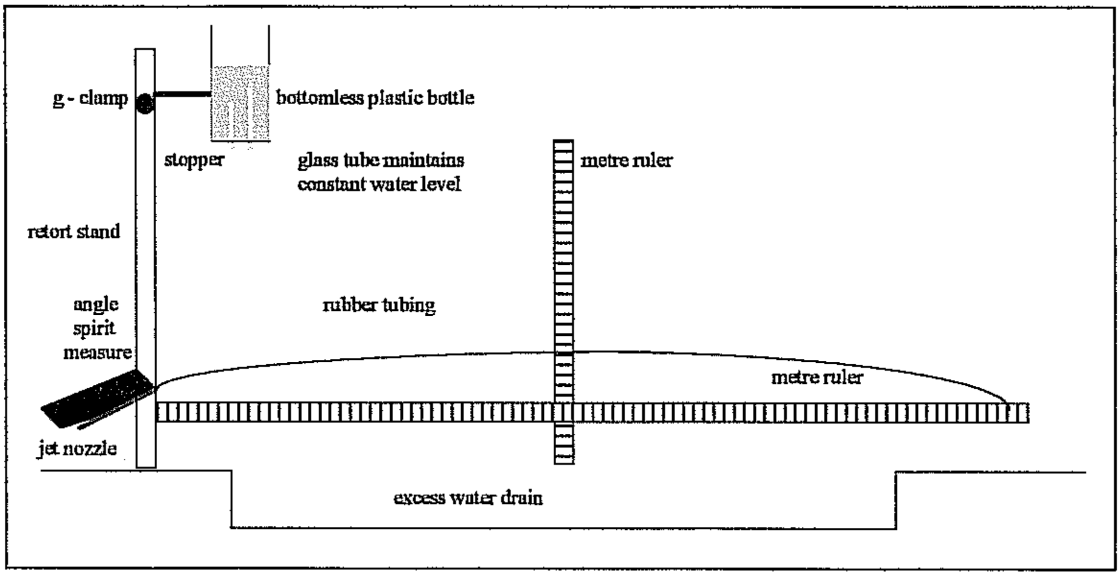

figure 1.1

In experiment 1 a constant flow of water was obtained by turning the tap on and setting the bottle at a designated height on the retort stand. The maximum horizontal and vertical distances of the projectile were measured and recorded. The angle was varied between 0° to 90°, in increments of 5°, using an angle dial on the spirit level attached to the nozzle. Results were graphed against theoretical values, determined using relevant equations

Experiment 2 was completed using the same procedure as above but H_A was increased, providing a higher velocity. The results were graphed against the determined theoretical values.

In experiment 3 the velocity remained constant and the horizontal displacements were measured for angles of 50°, 45°, 40°, and 35°. These distances were each measured again at 5 cm, 10 cm, 15 cm and 20 cm below the horizontal line of the nozzle. *(see figure 1.2)* The results were collated and analysed.

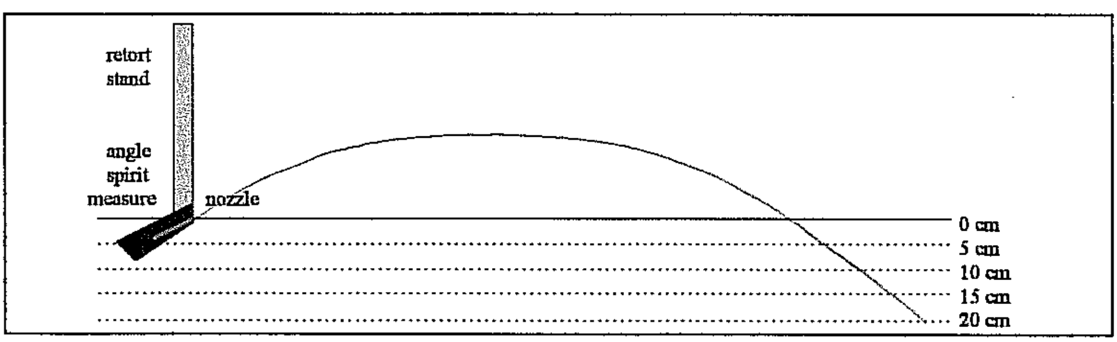

figure 1.2

Each of the experiments were repeated to obtain three concordant results sets which were averaged obtaining a more accurate result.

Results and Observations

Comparison of experimental and theoretical height.

In both experiments 1 and 2 the experimental results follow a similar curve to the theoretical data formulated. It is clear when comparing theoretical and experimental values of height, as the degree of the angle increases the accuracy of the experimental data decreases in comparison to the theoretical data. *(see figures; 2.1, 2.2)* This gradual increase in error becomes more evident as the angle increases above 35° in both experiments. This discrepancy between theoretical and experimental values as the angle increases is because the theoretical assumptions do not actually apply to the experiment, particularly the 9.8 ms^{-2} gravitational acceleration. Due to adhesion and friction forces the water does not accelerate at 9.8 ms^{-2} but rather at a lower value, hence decreasing the theoretically expected velocity. Thus the experimental projectile does not achieve in the tube the theoretically expected displacement vertically or horizontally. As friction is involved in the experiment (and not in the theoretical curve) the projectile will show a lower than theoretically expected displacement height. In each experiment an uncertainty of $\pm$ 1 mm was used to account for any error in reading measurements from the ruler.

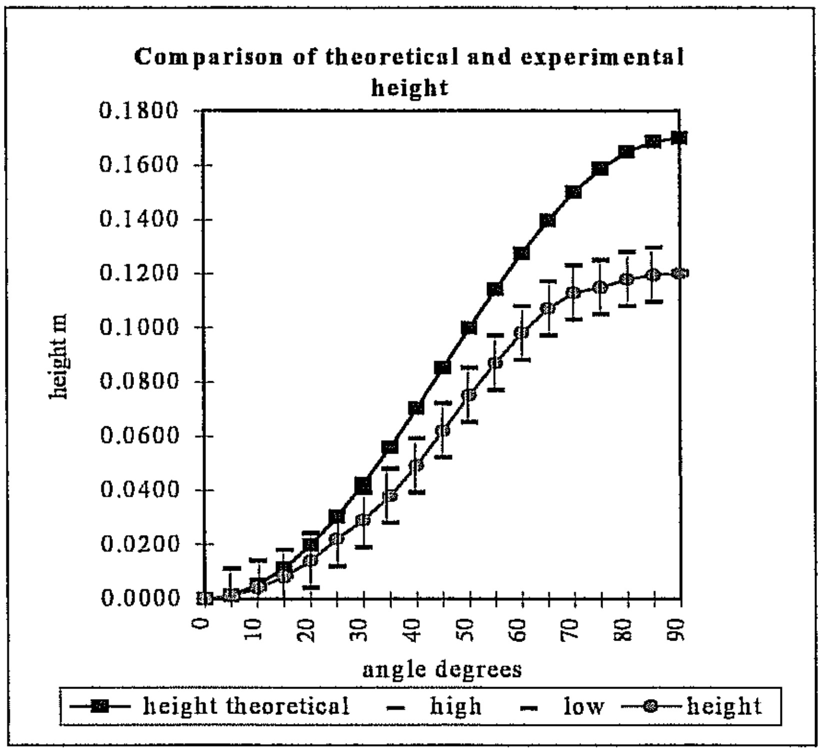

figure 2.1

$v = 1.8\ ms^{-1}$. *(see appendix 1.1 for data table)*

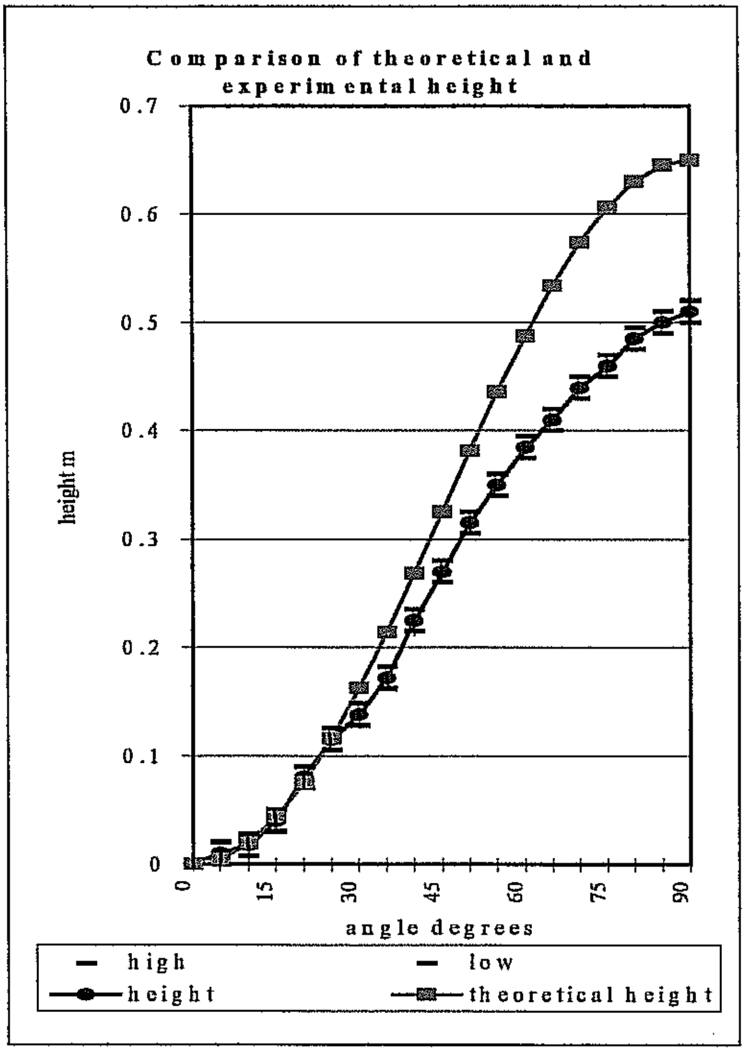

figure 2.2

v = 3.6 ms^{-1}.*(see appendix 1.2 for data table)*

Comparison of experimental and theoretical length.

When comparing experimental and theoretical values of length, both figure 3.1 and 3.2 show similar graphs. In both cases the experimental data produces a smaller parabolic shape compared to a larger more perfect theoretical parabola. At the extremities (0° - 15° and 85° - 90°) experimental and theoretical values are closest, depicting decreasing accuracy of the experiment as the angle moves towards 45° from both 0° and 90°. Once again when the departure angle was set where the projectile travelled the furthest, the difference between experimental and theoretical values was greatest due to lower than theoretical expected projectile velocity as previously discovered in experiment 1. A cause of the lower experimental values can also be accredited to the air resistance or drag force occurring through out the experiment.

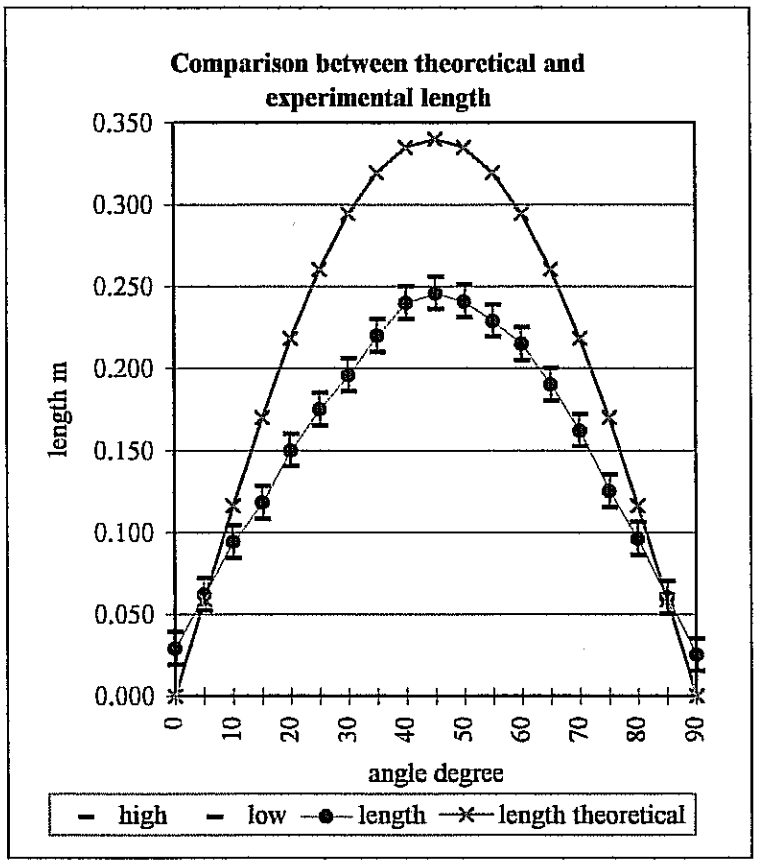

figure 3.1

v = 1.8 ms^{-1}. *(see appendix 2.1 for data table)*

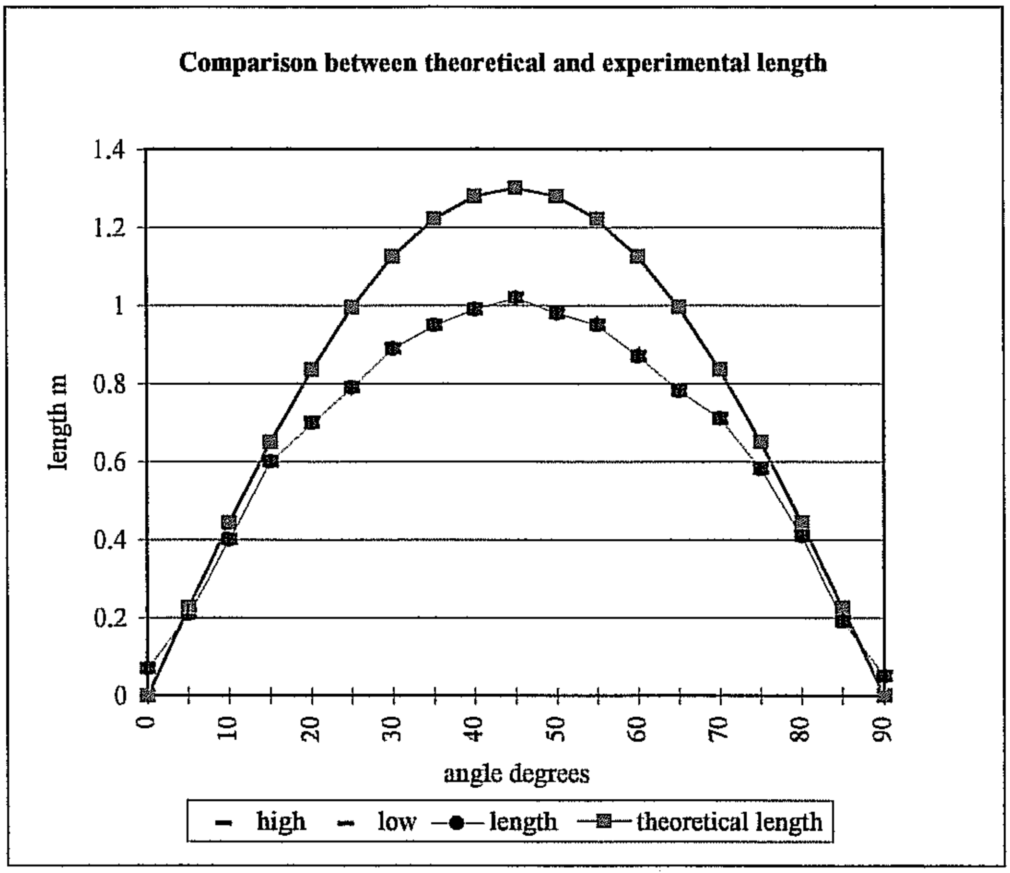

figure 3.2

$v = 3.6\ ms^{-1}$.*(see appendix 2.2 for data table)*

Figures 4.1 to 4.5, using 45° as an example, show that in a military situation where the velocity of a cannon is restricted to a certain level the horizontal displacement can be maximised by increasing the departure point of the nozzle above the reference plane. eg. locating a cannon on a hill. In experiment 3 instead of raising the height of the nozzle above the 0 cm reference plane, the reference plane was dropped by 5 cm each time.

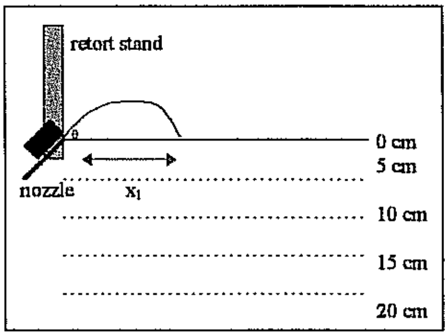

figure 4.1

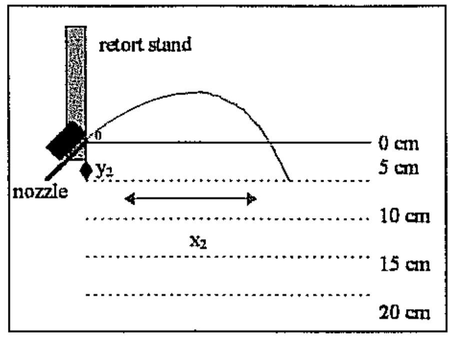

figure 4.2

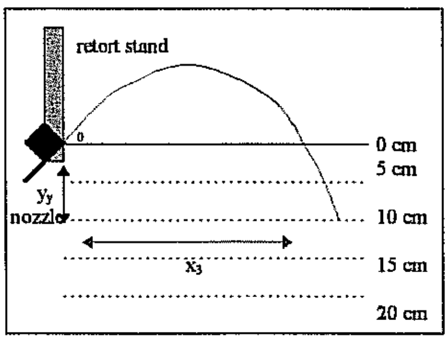

figure 4.3

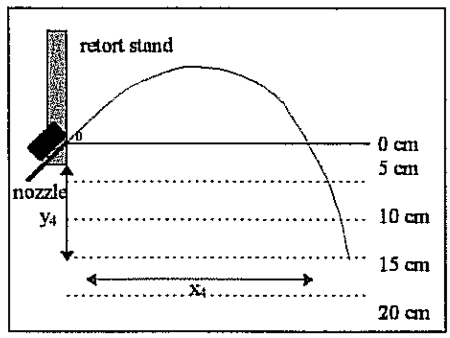

figure 4.4

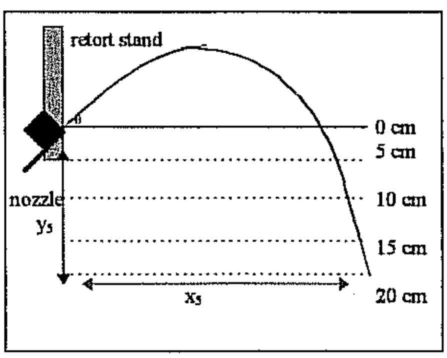

figure 4.5

The horizontal displacement of the projectile increased as the departure angle decreased for all values below the 0 cm reference plane. This was because the time at which the projectile was in it's parabolic flight increased, thus an increase in displacement occurs.

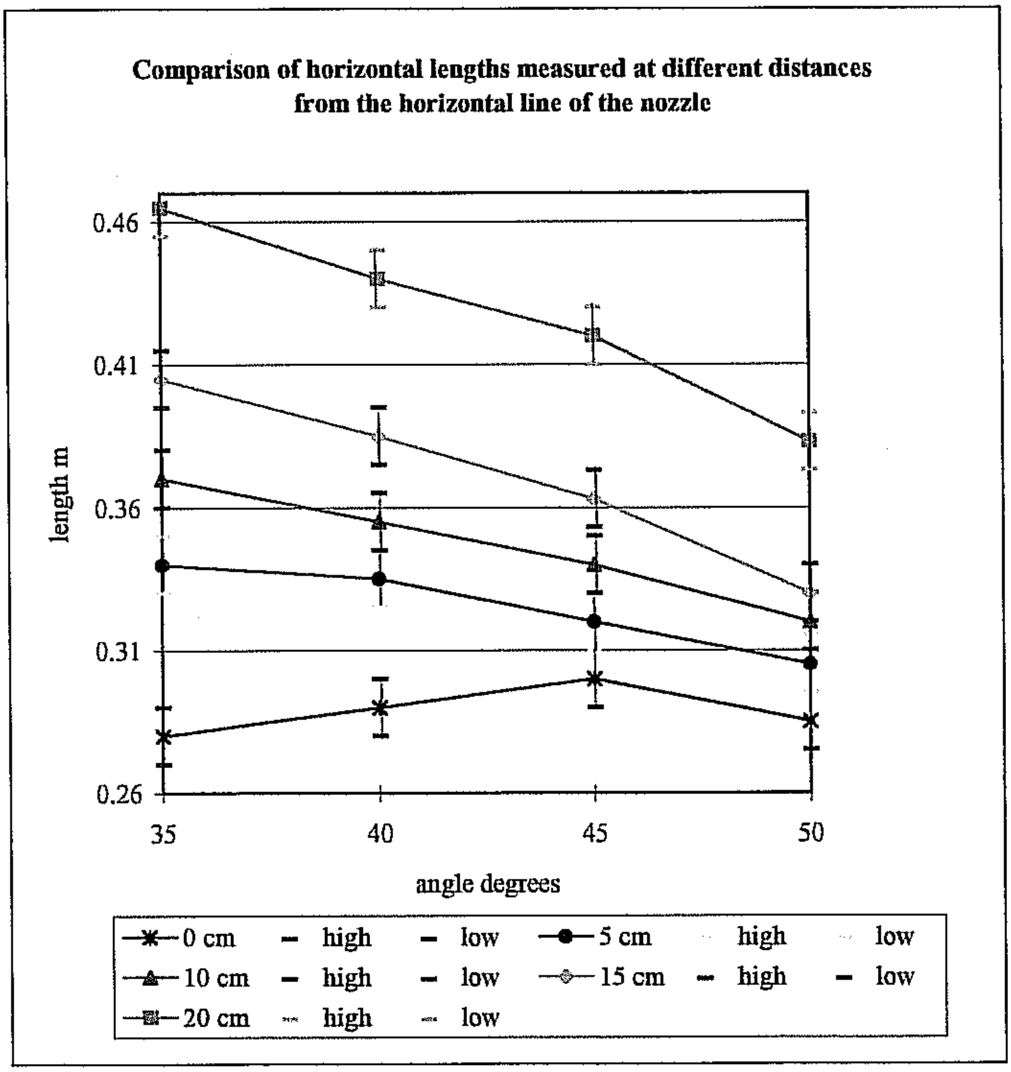

figure 4.6

$v = 2.4\ ms^{-1}$. *(see appendix 3.1 for data table)*

Deductions and Conclusions

Results from experiments 1 and 2 concluded that at constant velocity the maximum vertical height and maximum horizontal length of the projectile was found at 45°. It was also found that with increased velocity the projectile travelled further, in the both the horizontal and vertical direction.

When comparing theoretical and experimental height, it was found that the degree of accuracy decreased in comparison to the theoretical values as the angle increased. This is because air resistance(the theoretical equations assume vacuum conditions), and adhesion and friction in the tube causing the water to fall at less than theoretical 9.8 ms^{-2} gravitational acceleration. Thus, providing a lower velocity than theoretically expected.

When comparing the theoretical and experimental lengths the degree of accuracy was best at the extremities and decreased substantially as the angle approached 45° from both 0° and 90°. This discrepancy is again due to air resistance and lower than expected velocity.

In both cases the experimental data followed a similar curve to that produced by the theoretical data, but in all cases the experimental data was either on or below those values produced using the theoretical equations. This is because the theoretical data assumes an ideal situation where air resistance negligible for example in a vacuum.

In experiment 3 it was concluded that the displacement distance will be a maximum when, the departure angle of the projectile, is equal to 45° at the point of measurement. Also, as the vertical distance from the nozzle to the measuring point increased (below the 0 cm reference plane), the maximum length reached by the also increased. This is because as the vertical distance increases more time is available for the projectile to travel further. Each set of data series formed a section of a parabola, backing up the conclusions stated in experiment 1 and 2.

Analysis of Uncertainties

The discrepancies that occurred in experiments 1 and 2 can mainly be attributed to the calculated theoretical value for the departure velocity of the water. Using experiment 1 as an example, due to both adhesive and friction forces occurring as the water travelled down the tube the velocity is actually lower than the theoretical value expected from a water displacement height of 0.17 m together with an acceleration of 9.8 ms^{-2}. Instead if a height of 0.12 m is used to derive the theoretical curve, instead of the actual 0.17 m, the experimental curve much more closely approximates this 0.12 m resultant theoretical curve. While solely varying the displacement height simulates the apparent lower experimental velocity from the nozzle the actual reason for this lower value is that friction and adhesion forces reduces the acceleration of the water below theoretical gravity value, 9.8 ms^{-2}, which in turn produces a lower theoretical expected velocity. As the projectile height formula reduces to one not containing an acceleration parameter eg;

$$\text{vertical}_{\text{displacement}} = H_A * \sin^2\theta$$

it was not possible to apply a lower acceleration value, hence the lower height displacement value. The results are shown in figures 6.1 and 6.2.
(see appendix 6.1 and 6.2 for experimental data tables)

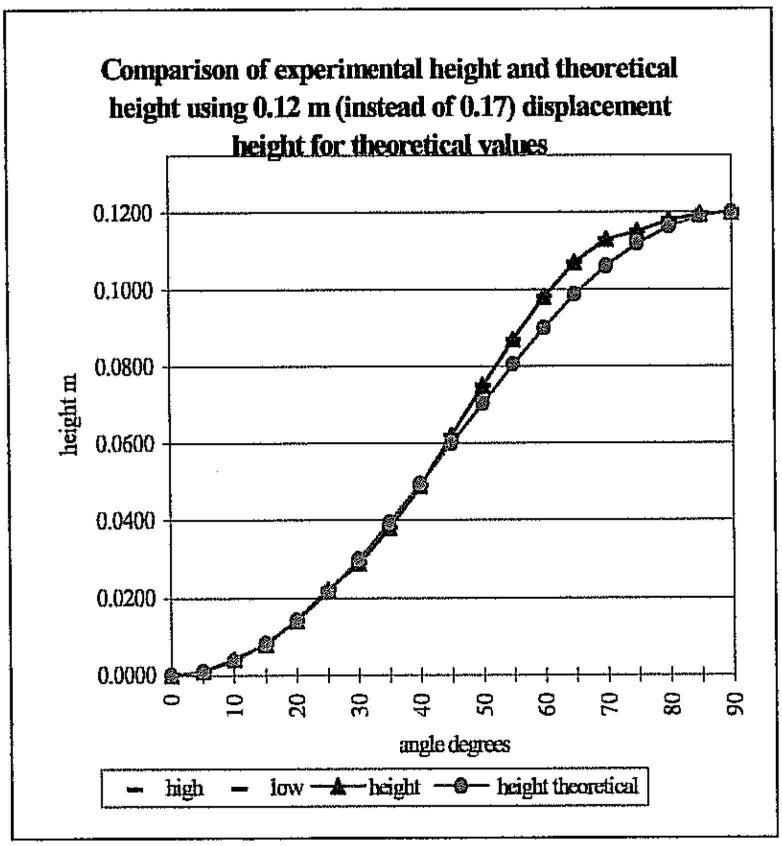

figure 6.1

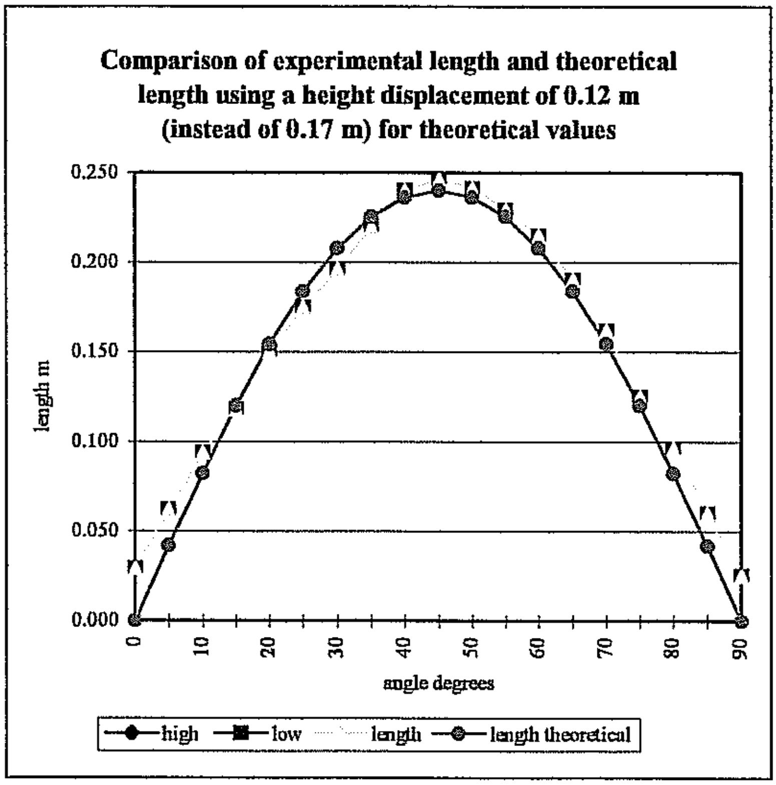
Comparison of experimental length and theoretical length using a height displacement of 0.12 m (instead of 0.17 m) for theoretical values
0.250
0.200
0.150
0.100
0.050
0.000
length m
0
10
20
30
40
50
60
70
80
90
angle degrees
high
low
length
length theoretical

figure 6.2

Acknowledgments

I would like to acknowledge the assistance of my prac. partner Marzena Godecki for ideas about how to go about solving various problems and my Dad for helping me in using *Excel.*

References

1. De Jong, E et al. *Physics Two.* Rigby Heinenmann, Victoria 1991
2. Siddons, C. *Experiments in Physics* Basil Blackwell 1988
3. Storen, A et al *Physics for Senior Students* Thomas Nelson Australia 1992
4. Halliday, D and Resnick, R *Fundamentals of Physics* 3rd Ed. John Wiley and Sons USA 1988
5. *Projectiles* Microsoft ® Encarta. 1995 Microsoft Corporation. 1995 Funk and Wagnells Corporation
6. Fogiel, Dr. *The Physics Problem Solver* Reaserch and Education Assoc. USA 1979
7. Tait, A et al. *A Guide to Yr 12 Physics.* Longman Sorret 1979

Appendices

Appendix 1.1 (see figure 2.1)

angle	0.01	uncertainty m		
degrees	high	low	height	height theoretical
0	0.0000	0.0000	0.0000	0.0000
5	0.0110	0.0010	0.0010	0.0013
10	0.0140	0.0040	0.0040	0.0051
15	0.0180	0.0080	0.0080	0.0114
20	0.0240	0.0040	0.0140	0.0199
25	0.0320	0.0120	0.0220	0.0304
30	0.0390	0.0190	0.0290	0.0425
35	0.0480	0.0280	0.0380	0.0559
40	0.0590	0.0390	0.0490	0.0702
45	0.0720	0.0520	0.0620	0.0850
50	0.0850	0.0650	0.0750	0.0998
55	0.0970	0.0770	0.0870	0.1141
60	0.1080	0.0880	0.0980	0.1275
65	0.1170	0.0970	0.1070	0.1396
70	0.1230	0.1030	0.1130	0.1501
75	0.1250	0.1050	0.1150	0.1586
80	0.1280	0.1080	0.1180	0.1649
85	0.1295	0.1095	0.1195	0.1687
90	0.1205	0.1195	0.1200	0.1700

Appendix 1.2 (see figure 3.1)

angle	0.01	uncertainty m		
degrees	high	low	length	length theoretical
0	0.039	0.019	0.029	0.000
5	0.072	0.052	0.062	0.059
10	0.104	0.084	0.094	0.116
15	0.128	0.108	0.118	0.170
20	0.160	0.140	0.150	0.219
25	0.185	0.165	0.175	0.260
30	0.206	0.186	0.196	0.294
35	0.230	0.210	0.220	0.319
40	0.250	0.230	0.240	0.335
45	0.256	0.236	0.246	0.340
50	0.251	0.231	0.241	0.335
55	0.239	0.219	0.229	0.319
60	0.225	0.205	0.215	0.294
65	0.200	0.180	0.190	0.260
70	0.172	0.152	0.162	0.219
75	0.135	0.115	0.125	0.170
80	0.106	0.086	0.096	0.116
85	0.070	0.050	0.060	0.059
90	0.035	0.015	0.025	0.000

Appendix 2.1 (see figure 2.2)

angle degrees	0.01 uncertainty m high	low	length	theoretical length
0	0.08	0.06	0.07	0.000
5	0.22	0.2	0.21	0.226
10	0.41	0.39	0.4	0.445
15	0.61	0.59	0.6	0.650
20	0.71	0.69	0.7	0.836
25	0.8	0.78	0.79	0.996
30	0.9	0.88	0.89	1.126
35	0.96	0.94	0.95	1.222
40	1	0.98	0.99	1.280
45	1.03	1.01	1.02	1.300
50	0.99	0.97	0.98	1.280
55	0.96	0.94	0.95	1.222
60	0.88	0.86	0.87	1.126
65	0.79	0.77	0.78	0.996
70	0.72	0.7	0.71	0.836
75	0.59	0.57	0.58	0.650
80	0.42	0.4	0.41	0.445
85	0.2	0.18	0.19	0.226
90	0.06	0.04	0.05	0.000

Appendix 2.2 (see figure 3.2)

angle degrees	0.01 uncertainty m high	low	height	theoretical height
0	0	0	0	0.0000
5	0.02	0	0.01	0.0049
10	0.0275	0.0075	0.0175	0.0196
15	0.05	0.03	0.04	0.0435
20	0.09	0.07	0.08	0.0760
25	0.125	0.105	0.115	0.1161
30	0.148	0.128	0.138	0.1625
35	0.182	0.162	0.172	0.2138
40	0.235	0.215	0.225	0.2686
45	0.28	0.26	0.27	0.3250
50	0.325	0.305	0.315	0.3814
55	0.36	0.34	0.35	0.4362
60	0.395	0.375	0.385	0.4875
65	0.42	0.4	0.41	0.5339
70	0.45	0.43	0.44	0.5740
75	0.47	0.45	0.46	0.6065
80	0.495	0.475	0.485	0.6304
85	0.51	0.49	0.5	0.6451
90	0.52	0.5	0.51	0.6500

Appendix 3.1 (see figure 4.6)

	measuring distance vertically down from nozzle				0.01 uncertainty m	
angle	0 cm	high	low	5 cm	high	low
35	0.28	0.29	0.27	0.34	0.35	0.33
40	0.29	0.3	0.28	0.335	0.345	0.325
45	0.3	0.31	0.29	0.32	0.33	0.31
50	0.285	0.295	0.275	0.305	0.315	0.295

10 cm	high	low	15 cm	high	low
0.37	0.38	0.36	0.405	0.415	0.395
0.355	0.365	0.345	0.38	0.39	0.37
0.34	0.35	0.33	0.35	0.36	0.34
0.32	0.33	0.31	0.32	0.33	0.31

20 cm	high	low
0.465	0.475	0.455
0.44	0.45	0.43
0.42	0.43	0.41
0.375	0.385	0.365

Appendix 4.1 (see figure 4.1)

angle	0.01	uncertainty m		9.8
degrees	high	low	height	height theoretical
0	0.0000	0.0000	0.0000	0.0000
5	0.0005	0.0005	0.0005	0.0009
10	0.0010	0.0010	0.0010	0.0036
15	0.0090	0.0090	0.0090	0.0080
20	0.0190	0.0190	0.0190	0.0140
25	0.0220	0.0220	0.0220	0.0214
30	0.0290	0.0290	0.0290	0.0300
35	0.0380	0.0380	0.0380	0.0395
40	0.0470	0.0470	0.0470	0.0496
45	0.0650	0.0650	0.0650	0.0600
50	0.0750	0.0750	0.0750	0.0704
55	0.0840	0.0840	0.0840	0.0805
60	0.0980	0.0980	0.0980	0.0900
65	0.1070	0.1070	0.1070	0.0986
70	0.1130	0.1130	0.1130	0.1060
75	0.1150	0.1150	0.1150	0.1120
80	0.1180	0.1180	0.1180	0.1164
85	0.1195	0.1195	0.1195	0.1191
90	0.1205	0.1195	0.1200	0.1200

Appendix 4.2 (see figure 5.2)

angle	0.01	uncertainty m		
degrees	high	low	length	length theoretical
0	0.029	0.029	0.029	0.000
5	0.062	0.062	0.062	0.042
10	0.094	0.094	0.094	0.082
15	0.118	0.118	0.118	0.120
20	0.162	0.162	0.162	0.154
25	0.175	0.175	0.175	0.184
30	0.196	0.196	0.196	0.208
35	0.210	0.210	0.210	0.226
40	0.240	0.240	0.240	0.236
45	0.246	0.246	0.246	0.240
50	0.241	0.241	0.241	0.236
55	0.229	0.229	0.229	0.226
60	0.219	0.219	0.219	0.208
65	0.195	0.195	0.195	0.184
70	0.162	0.162	0.162	0.154
75	0.125	0.125	0.125	0.120
80	0.102	0.102	0.102	0.082
85	0.060	0.060	0.060	0.042
90	0.000	0.000	0.000	0.000

CAT 1 : EXTENDED PRATICAL INVESTIGATION
ARTICLE

THE FLIGHT OF BALLS - BASKETBALLS

The Flight of Balls - Basketball

When throwing an object in a direction, both the angle and the velocity at which the ball is thrown are factors in getting the ball to it's eventual destination. When projecting any object, trajectory path is formed. An ideal situation, where wind resistance is negligible, the trajectory path produces a perfect parabola.[1] *see figure 1.1*

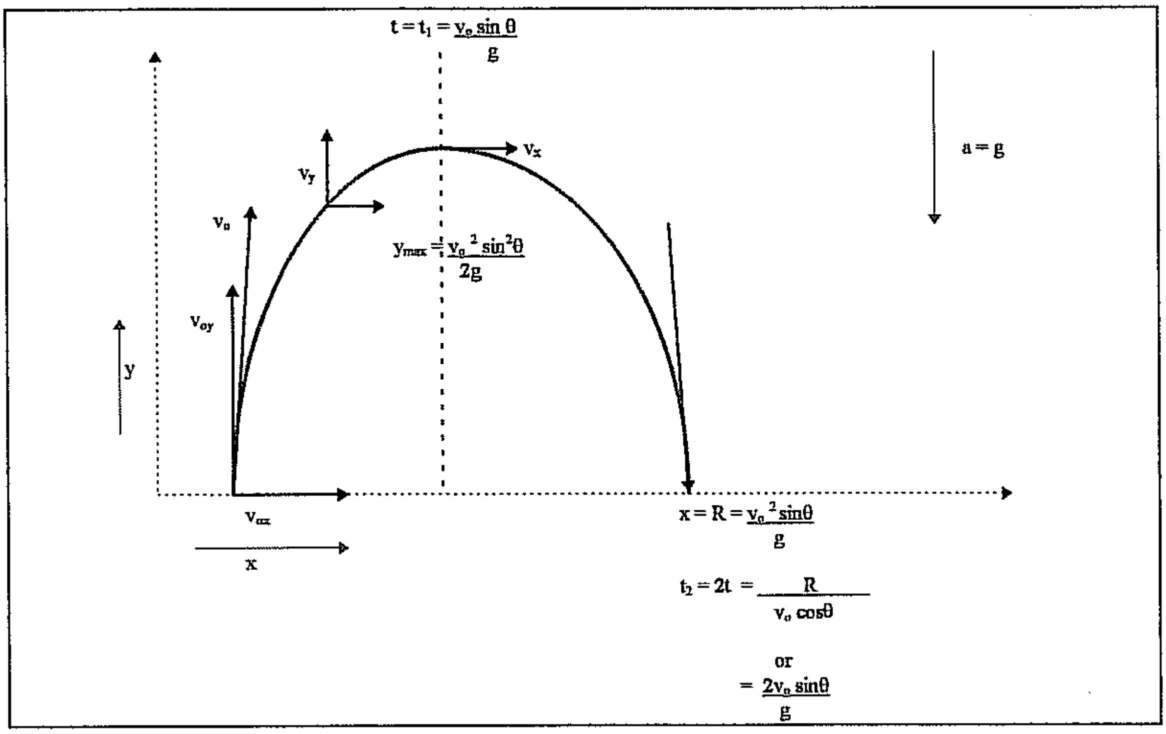

figure 1.1

$v_{ox} = v_o \cos\theta$

$v_{oy} = v_o \sin\theta$

$v_x = v_{ox}$

$v_y = v_{oy} - gt$

$x = v_o \cos\theta t$

$y = v_o \sin\theta t - 1/2gt^2$

[1] De Jong, E et al. *Physics Two.* Rigby Heinenmann, Victoria 1991 p.190

Vertical component of motion

initial velocity; $v_i = v_o \sin\theta$

acceleration for the vertical component (upwards is +ve);

$$a = -g$$

$$\therefore v_f = v_o \sin\theta - gt$$

$$\text{Using } y = v_i t + 1/2at^2$$

$$\therefore y = v_o \sin\theta t - (g/2)t^2$$

time taken to reach maximum height(t_1);

$$\text{Using } v_f = v_o + at, \text{ where } v_f = 0$$

$$\therefore 0 = v_o \sin\theta - gt_1$$

$$\therefore gt_1 = v_o \sin\theta$$

$$\therefore t_1 = \frac{v_o \sin\theta}{g}$$

using symmetry of the parabolic curve, total flight time;

$$t_2 = 2t_1$$

maximum height of projectile;

$$s = v_i t + 1/2at^2$$

where $s = H$ or y_{max}

$$\therefore H = v_o \sin\theta t_1 - 1/2gt_1^2$$

$$\text{where } t_1 = \frac{v_o \sin\theta}{g}$$

$$\therefore \mathbf{H = \frac{v_o^2 \sin^2\theta}{2g}}$$

Horizontal Component of Motion

$$\text{If } v_i = v_o \cos\theta \quad \text{and } a = 0$$

$$\therefore v_x = v_o \cos\theta \;\&\; x = v_o \cos\theta t$$

The maximum range of the projectile (R);

$$R = v_x t_2$$

$$\text{as } v_x = v_o \cos\theta \text{ and } t_2 = 2 \times \frac{v_o \sin\theta}{g}$$

$$\therefore R = v_o \cos\theta \times \frac{2v_o \sin\theta}{g}$$

$$\therefore \mathbf{R = \frac{v_o^2 \sin 2\theta}{g}}$$

where $g = 9.8 \text{ ms}^{-2}$
v = departure velocity
θ = departure angle
R = range

By varying the departure angles of projection different horizontal displacements can be produced. *see figure 1.2* At 45° the projectile travels further because both the horizontal and vertical components are equal. At angles above and below 45° the two components are unequal, thus a shorter distance is travelled.

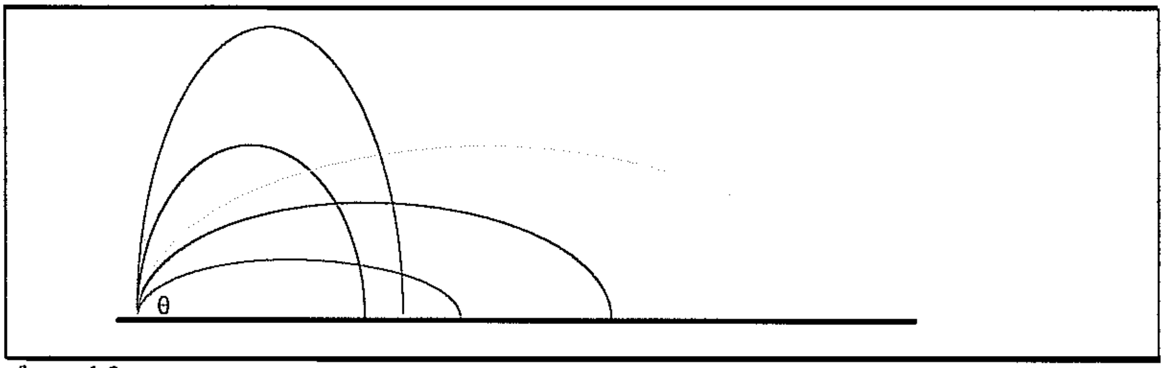

figure 1.2

In a real life situation air resistance or drag force has an effect on the trajectory path, by decreasing both the maximum horizontal and vertical displacement. In most situations the drag force is proportional to the cross sectional area of the object and the square of it's speed. In effect the drag force will increase with an increase in speed. ie. a ball travelling at 60 ms^{-1} will have four times as much air resistance as a ball travelling at 30 ms^{-1}.[2] A measure of how much an object will be effected by drag force is equal to the ratio ;

$$\frac{\textit{cross sectional area}}{\textit{mass}}$$

In basketball angles and velocities are considered when shooting from a given point. Figure 1.3 shows a shot being taken from a standstill, *P* distance from the ground, *D* distance horizontally from the ring and *h* distance vertically from the ring, thrown at an angle of θ_o and velocity of v_o.

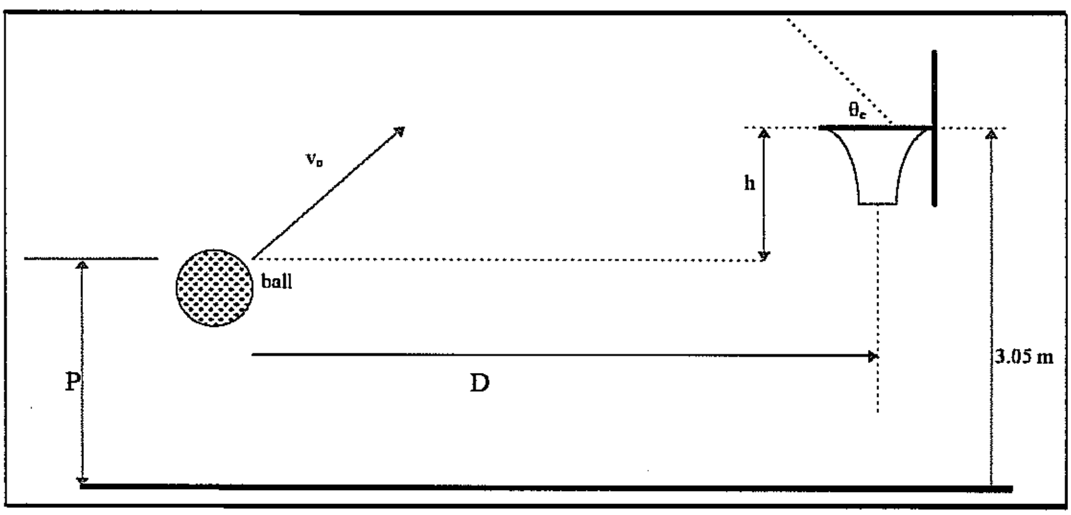

figure 1.2

[2] De Jong, E et al. *Physics Two.* Rigby Heinemann, Victoria 1991 p.191

Using the equations derived in the first part from the above diagram x = D and y = h the equation is as follows;

$$h = D \tan\theta - \frac{g D^2}{2 v_o^2 \cos^2\theta}$$

Thus the relationship between any x and y point is;

$$y = x \tan\theta - \frac{g x^2}{2 v_o^2 \cos^2\theta}$$

As the ball is being thrown to a target higher than the departure height, depending on the distance away 45° is not the optimum angle; a departure angle less than 45° would be suitable if a fair distance away and an angle greater than 45° if close to the ring. In both of these cases the departure velocity must also be considered.

Basketball depends a lot on the departure velocity and the departure angle of the ball when shooting. Due to the positions of the backboard behind the net, there is a larger range for both the optimum departure angles and velocities at which a person can throw the ball utilising the advantage that the ball may rebound off the backboard and drop in.

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