ANALYSIS

Data

Spin Rate (±3 rad/s)	Graph of Y			Graph of X		Time	
	A	B	C	m	b	Initial	Final
0	0.0298	-11.94	1195	108.5	-21200	195.5	199.0
11	0.1246	-55.83	6254	138.0	-31240	226.3	229.8
14	-0.5285	131.8	-8213	140.8	-17250	122.5	126.0
29	-0.7679	250.9	-20480	141.3	-22730	160.9	164.4
72	0.2720	-1130	11730	134.0	-28030	209.1	212.6
97	1.528	-1589	413000	119.0	-61810	519.6	523.1
99	1.373	-1554	439900	138.4	-78390	566.3	569.8
101	0.7347	-1165	461900	158.9	-126500	796.0	799.5
102	0.9991	-483.1	58390	136.2	-33090	242.8	246.3
106	1.815	-1467	296400	225.0	-91140	405.1	408.6
108	1.768	-507.9	36480	152.6	-21990	144.0	147.5
109	0.9766	-1036	274900	154.0	-82080	532.8	536.3
111	1.723	-1351	264900	116.3	-45600	392.1	395.6
114	1.962	-2181	605900	128.1	-71180	555.8	559.3
118	4.704	-3800	767500	205.0	-82670	403.3	406.8
130	2.034	-2929	1054000	180.8	-130300	720.8	724.3
135	0.9491	-1294	441100	228.2	-156500	685.8	689.3
140	1.666	-380.8	21770	134.5	-15450	114.9	118.4
151	2.677	-1189	132100	135.1	-29990	222.0	225.5
164	1.900	-1940	495400	199.8	-102300	512.1	515.6

Table 1: The raw data table of the collected values all rounded to four significant figures. As seen above time was a constant variable in the experiment; however, LoggerPro was claiming that one second was equivalent to 30 frames, which was not the case. Therefore, the time range, 3.5 seconds was multiplied by a factor of $\frac{30\ frames}{600\ frames}$(simplified to $\frac{1}{20}$), since the camera was set at 600 frames per second. After the calculation, the time range was found to be 0.175 ± 0.001 seconds. Analyzing one trial three times and dividing the range by a factor of two achieved the uncertainty of the spin rate. This uncertainty was applied to all the other trials.

Data Processing

Sample Calculations

1. **Spin Rate**

$$Spin\ Rate = \frac{2n\pi}{\frac{Range\ of\ frames\ for\ n\ revolutions}{600\ frames}}$$

where n is the number of revolutions the ball spun within a specific number of frames.

$$= \frac{2\pi}{\frac{3544 - 3517}{600}}$$

$$= 139.625 = 137 \frac{rad}{s}$$

2. Spin Rate Uncertainty

$$Uncertainty = \frac{Maximum\ Value - Minimum\ Value}{2}$$

$$= \frac{144.997 - 139.626}{2}$$

$$= 2.6855 \ = \pm \frac{3\ radians}{second}$$

3. Time Uncertainty

$$Uncertainty = \frac{Range}{2}$$

$$= \frac{\frac{1}{600}}{2}$$

$$= \frac{1}{1200}$$

$$= 0.000833 \ = \pm 0.001\ s$$

Sample Graph

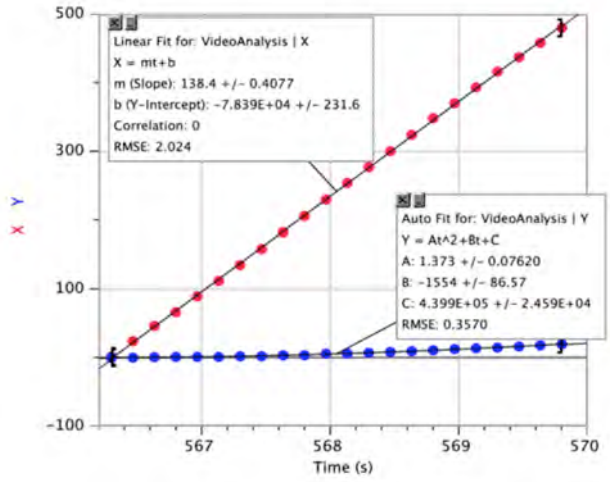

Figure 4: Sample graph showing the two fits made in order to obtain the values of *D* and *x*. The coefficient values shown in the graphs were used in determining the values as explained in the procedure.

Raw Data Table

Spin Rate (±3 rad/s)	D (±2 pixels)	x (±30 pixels)
0	0	380
11	4	480
14	2	490
29	4	490
72	6	470
97	15	420
99	21	480
101	25	560
102	19	480
106	35	790
108	26	530
109	28	540
111	22	410
114	24	450
118	27	720
130	36	630
135	39	800
140	28	470
151	31	470
164	44	700

Table 2: The values of *D* and *x* were left in pixels since they were going to be written as ratios and converting pixels into meters would ultimately give the same values. Uncertainties were calculated by analyzing one trial three times and dividing the range of answers by two.

Sample Calculations

4. ***D* Value**

$$D = \left(At_f^2 + Bt_f + C\right) - \left(At_i^2 + Bt_i + C\right)$$

$$= (1.666(118.4^2) - 380.8(118.4) + 21770) - (1.666(114.9^2) - 380.8(114.9) + 21770)$$

$$= 27.5723\ pixels$$

5. ***x* Value**

$$x = \left(mt_f + b\right) - (mt_i + b)$$

$$= (134.5(118.4) - 15450) - (134.5(114.9) - 15450)$$

$$= 470.75\ pixels$$

6. Uncertainty of D

$$Uncertainty = \frac{Maximum\ Value - Minimum\ Value}{2}$$

$$Maximum\ Value = (1.894(118.4^2) - 433.1(118.4) + 24750) - (1.894(114.9^2) - 433.1(114.9) + 24750)$$

$$Minimum\ Value = (1.666(118.4^2) - 380.8(118.4) + 21770) - (1.666(114.9^2) - 380.8(114.9) + 21770)$$

$$= \frac{30.6957 - 27.5723}{2}$$

$$= 1.5617 \quad = \pm 2$$

7.* Uncertainty of *x

$$Uncertainty = \frac{Maximum\ Value - Minimum\ Value}{2}$$

$$Maximum\ Value = (151.8(118.4) + 17440) - 151.8(114.9) + 17440))$$

$$Minimum\ Value = ((134.5(118.4) + 15450) - (134.5(114.9) + 15450)$$

$$= \frac{531.3 - 470.8}{2}$$

$$= 30.275 \quad = \pm 30$$

Final Table

Spin Rate (±3 rad/s)	D/x (±0.02)	Spin Rate (±3 rad/s)	D/x (±0.02)
0	0.00	108	0.05
11	0.01	109	0.05
14	0.00	111	0.05
29	0.01	114	0.05
72	0.01	118	0.05
97	0.04	130	0.06
99	0.04	135	0.05
101	0.05	140	0.06
102	0.04	151	0.07
106	0.04	164	0.06

Table 3: Final table of the spin rate and $\frac{D}{x}$ values.

Sample Calculations

8. **$\frac{D}{x}$ value** $\frac{D}{x} = \frac{28}{471}$

$= 0.059448 \quad = 0.06$

9. **Uncertainty of $\frac{D}{x}$**

$$Uncertainty = \frac{Maximum\ Value - Minimum\ Value}{2}$$

$$= \frac{\left(\frac{30}{440}\right) - \left(\frac{26}{800}\right)}{2}$$

Results

Final Graph

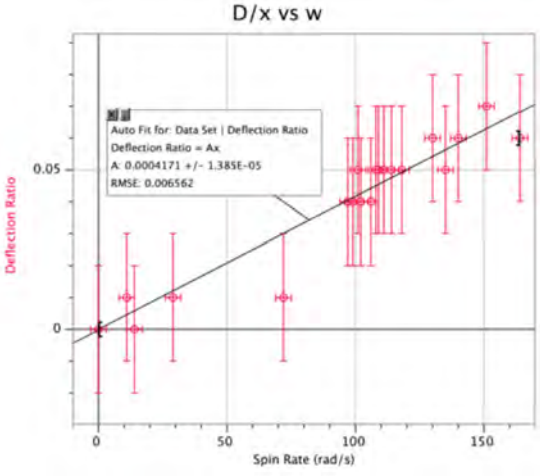

Figure 5: Final proportional graph of the relationship between spin rate and the deflection ratio.

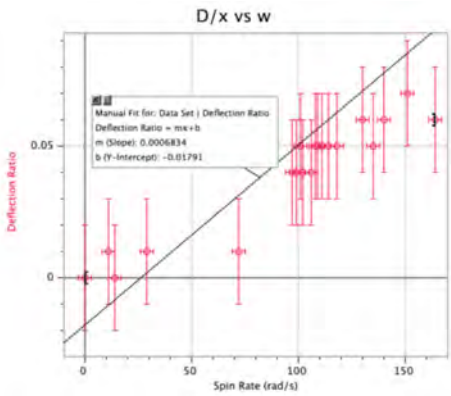

Figure 6: Linear graph of highest possible slope.

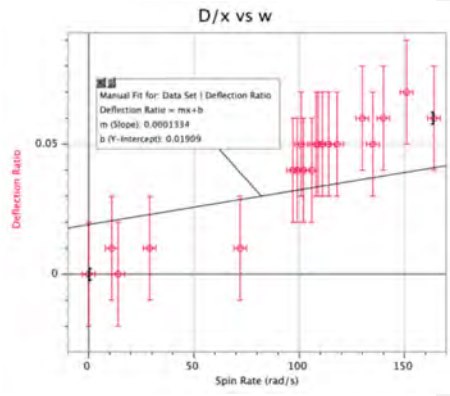

Figure 7: Linear graph of lowest possible slope.

Sample Calculations

10. Slope Uncertainty

$$Uncertainty = \frac{Maximum\ Value - Minimum\ Value}{2}$$

$$= \frac{0.0006834 - 0.0001334}{2}$$

$$= 0.000275$$

$$= \pm 0.0003$$

11. Y-intercept Uncertainty

$$Uncertainty = \frac{Maximum\ Value - Minimum\ Value}{2}$$

$$= \frac{0.01909 - (-0.01791)}{2}$$

$$= 0.0185$$

$$= \pm 0.02$$

Final Equation

$$\frac{D}{x} = (\mathbf{0.0004 \pm 0.0003}\ \boldsymbol{rad^{-1}})\boldsymbol{\omega} + (\mathbf{0.00 \pm 0.02}) \qquad \text{[Equation 3]}$$

12. Proportionality Constant (Based on theoretical equation from cited source)

$$Proportionality\ Constant = \frac{\pi R^3 \rho t}{m}$$

$$= \frac{\pi(0.02^3 m^3)(1.1841 kg m^{-3})(0.175 s)}{0.00236}$$

$$= 0.002207\ s$$

13. Uncertainty of Proportionality Constant

$$Uncertainty = \frac{Maximum\ Value - Minimum\ Value}{2}$$

$$= \frac{\frac{\pi(0.0201^3 m^3)(1.1881 kg m^{-3})(0.176 s)}{0.00235} - \frac{\pi(0.0199^3 m^3)(1.1802 kg m^{-3})(0.174 s)}{0.00237}}{2}$$

$$= 0.000062 \quad = \pm 0.00006$$

Final Value of Theoretical Proportionality Constant

$$0.00221 \pm 0.00006$$

Comment [9]: The report shows evidence of full and appropriate consideration of the impact of measurement uncertainty on the analysis.

Comment [10]: Appropriate and sufficient data processing is carried out with **the accuracy** required to enable a conclusion to the research question to be drawn that is fully **consistent** with the experimental data

Interpretation of the Results

The results of the data processing show that there is a proportional relationship between the spin rate and the deflection ratio. The proportionality constant between the spin rate and the deflection ratio is experimentally shown to be $0.0004 rad^{-1}$, meaning the deflection ratio is 0.0004 times the spin rate in radians. The uncertainty in the proportionality constant (0.0003) is roughly 75% of the estimated value, implying high levels of uncertainty in the equation derived to model the situation.

Comment [11]: The processed data is correctly interpreted so that a completely valid and detailed conclusion to the research question can be deduced.