TOM & JERRY
VS.
THE LAWS OF PHYSICS

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Note : This version of the Tom and Jerry report was partially edited by Priscilla Laws for physical correctness.

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Purpose:

It has been discovered in the past that the laws of physics do not hold true in cartoons. We analyzed two falling scenes and one collision scene taken from Tom and Jerry cartoons. The purpose of our project was to analyze these cartoons to determine if the acceleration of a falling object (Jerry and a vase) is -9.8 m/s/s in Tom and Jerry's cartoon world. We also analyzed a collision between Tom and Spike to see if the forces between Spike and Tom are equal and opposite. We also looked at whether Tom's initial kinetic energy was sufficient to create the gravitational potential energy rise of Tom and Spike after the collision.

Summary of Relevant Theories and Equations:

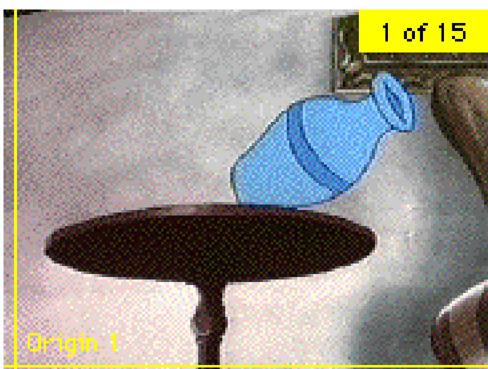
In the first two videos we used the theory that all objects falling freely close to the surface of the Earth without encountering drag forces of air resistance appear in reality to fall with an acceleration of -9.8m/s/s. The equation describing the motion of a freely falling object should be $y = -\frac{1}{2} a_g t^2 + v_{oy} t + y_0$.

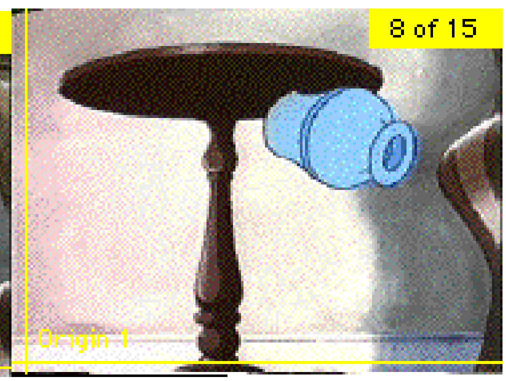
In the third video we wanted to analyze a collision to see if momentum and mechanical energy were conserved. However, we realized that the collision between Tom and Spike occurred with Spike being in contact with the ground, so they were not isolated for the purpose of testing conservation of momentum. Instead we decided to see if the forces between them during the collision seemed to obey Newton's Third Law. We also wanted to compare Jerry's initial kinetic energy to the rise in potential energy of Tom and Spike at the end of their collision.

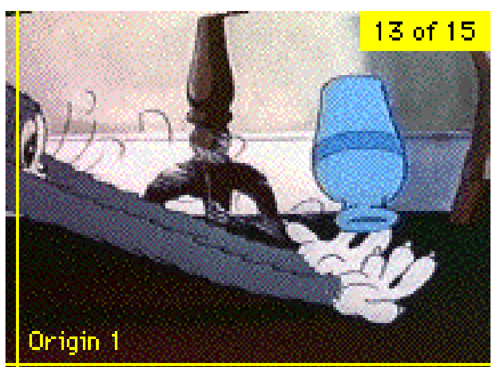
Procedures and Equipment:

In starting this project we rented Tom and Jerry cartoons and transferred three scenes onto VideoPoint. We estimated masses and heights using real life examples.

Video 1 : A vase falling from a table approximately 35" tall.



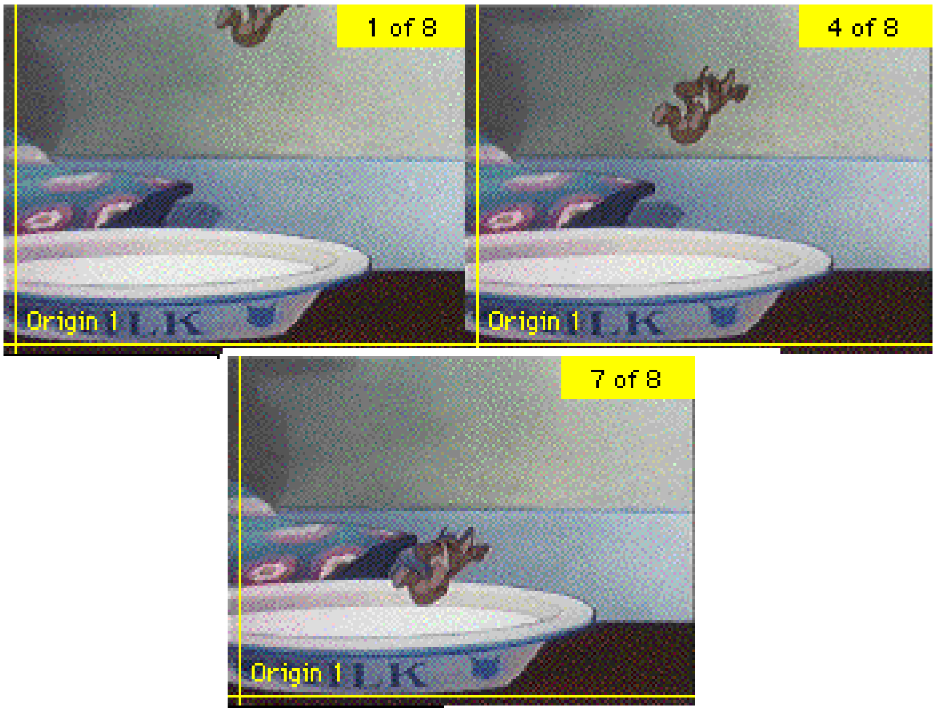




For this video we had to find an origin point that we could view throughout the movie since the background was moving. After this we were able to take points on the vase and transfer them onto Excel

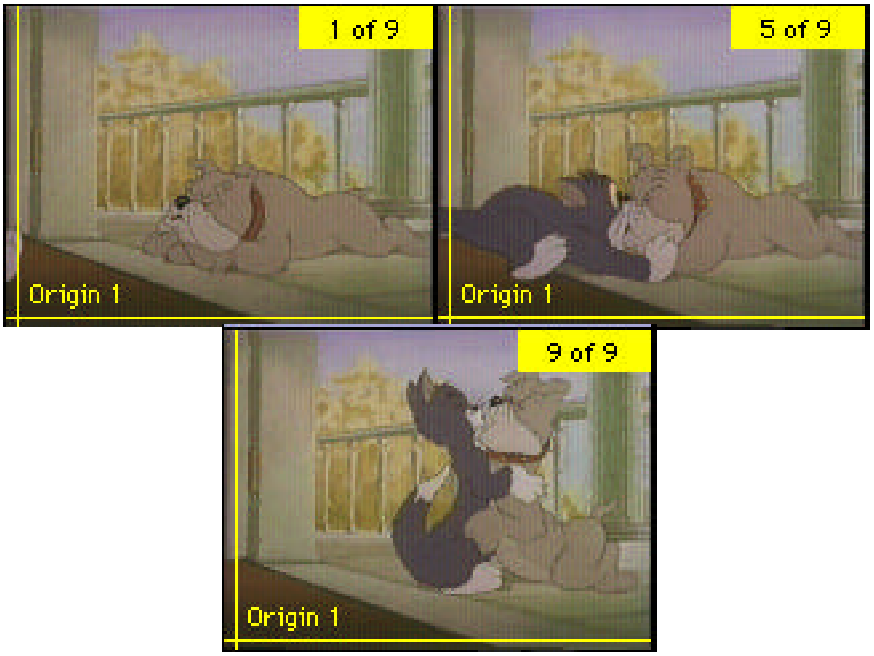
5 to be further analyzed. By adjusting the height of the table to be 35" we were able to get a physically reasonable result.

Video 2 : Jerry falling into a bowl of milk.



In this video the background was uniform so we did not have to move the origin. We estimated that the height of the milk bowl was 0.05 meters. We then took data points of Jerry and put it into Excel 5 and analyzed it from there.

Video 3: A collision between Tom and Spike.



In this video the background was uniform so we kept the origin fixed. We then measured the distance from the floor to the top of the first hinge in Tome's 104 main door. We then used that height to use the hinge in the movie to scale. Then we took data points that we transferred onto Excel to analyze the forces between Jerry and Spike during their collision and the potential energy they gain after the collision.

Data and Calculations:

Movie 1: Data Points; Falling Vase

Time (s)	y:Position (m)	Velocity (m/s)
0.033	-0.049	
0.067	-0.073	-0.73
0.100	-0.098	-0.73
0.133	-0.137	-1.19
0.167	-0.195	-1.74
0.200	-0.275	-2.38
0.233	-0.366	-2.75
0.267	-0.458	-2.74
0.300	-0.556	-2.93
0.333	-0.666	-3.30
0.367	-0.770	-3.11

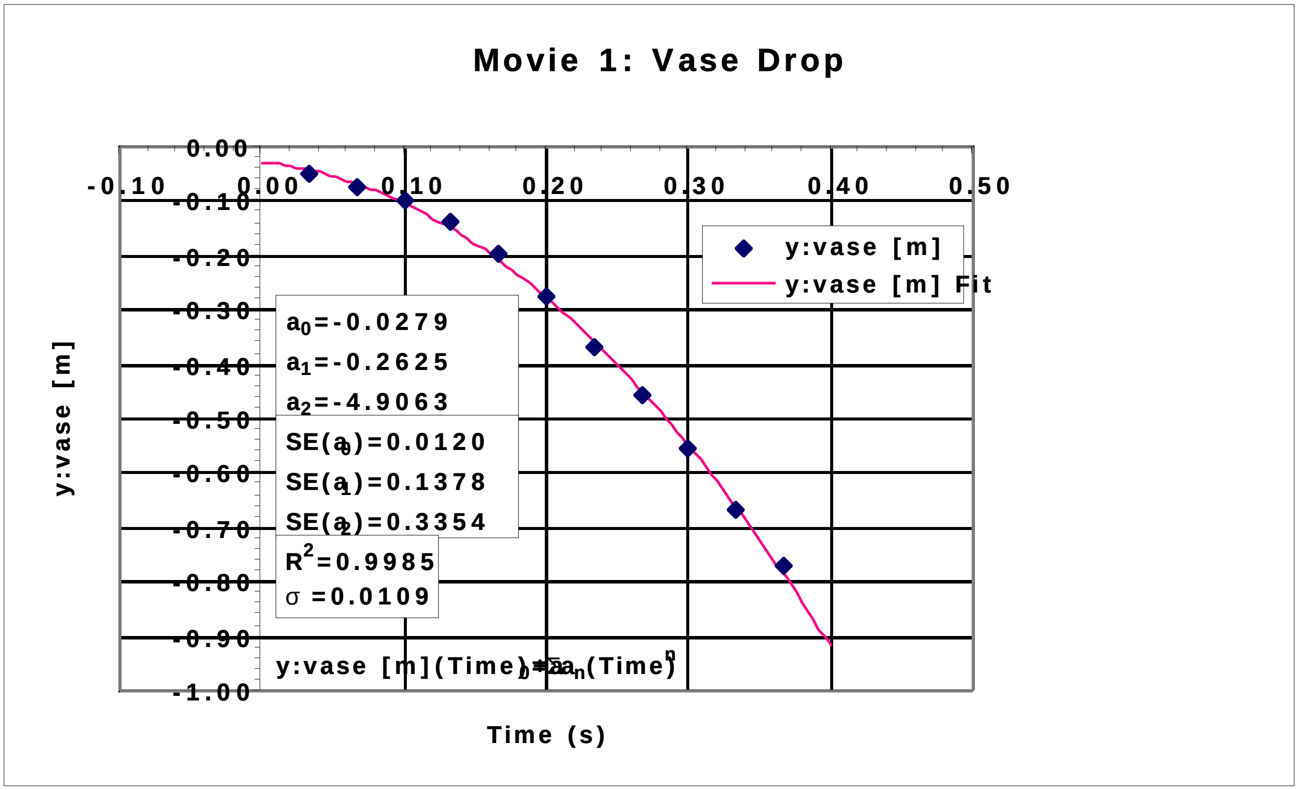
We calculated the average velocity between frames using the definition of average velocity between two times t_1 and t_2 as

$$y = -\tfrac{1}{2} a_g t^2 + v_{oy} t + y_0$$

$$E_{pot} = m_{Tom} a_g h_{Tom} + m_{Spike} a_g h_{Spike} \qquad v_{avg} = \frac{y_2 - y_1}{t_2 - t_1}$$

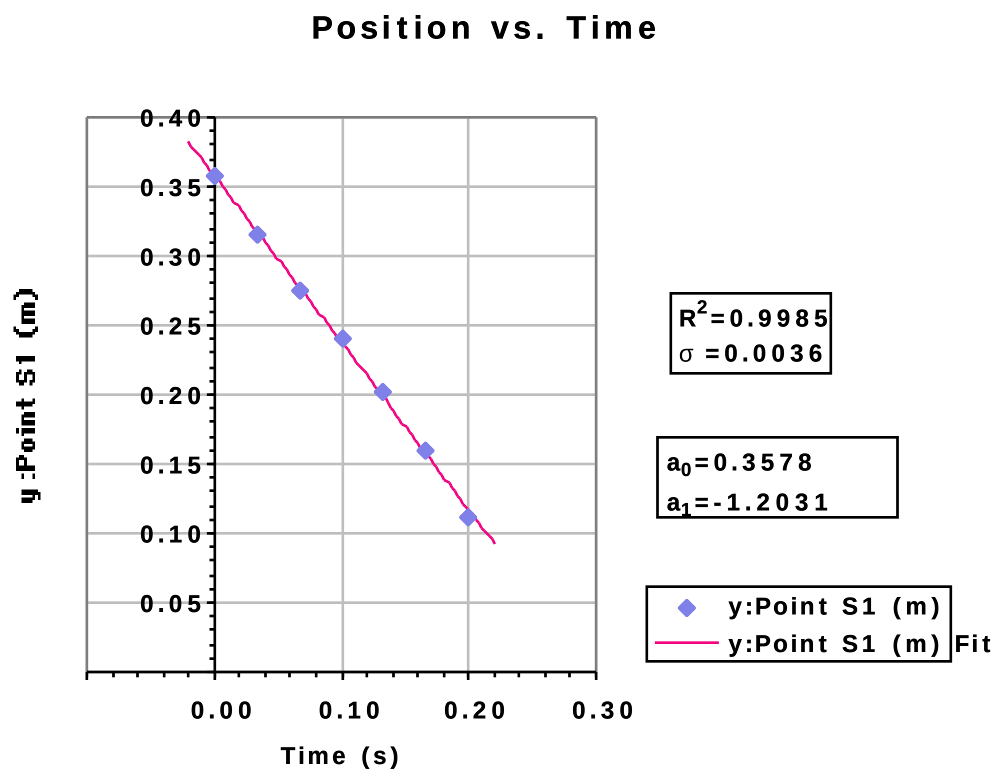
where y_1 and y_2 represent the vertical positions of the falling vase. Since the average velocity seemed to be increasing from frame to frame we did a quadratic fit on the y vs. t data under the assumption that $y = -\tfrac{1}{2} a_g t^2 + v_{oy} t + y_0$ for a freely falling object.

By adjusting the table height to about 35" in the movie we were able to obtain an excellent fit with a value for the y component of acceleration of the vase of $a_y = 2\,(-4.9) = -9.8$ m/s^2. This is shown in the graph that follows.



<u>**Movie 2 Data Points; Falling Jerry**</u>

Time (s)	Y Position (m)	Velocity (m/s)
0.00	0.36	-1.27
0.03	0.32	-1.19
0.07	0.28	-1.06
0.10	0.24	-1.17
0.13	0.20	-1.26
0.17	0.16	-1.42
0.20	0.11	



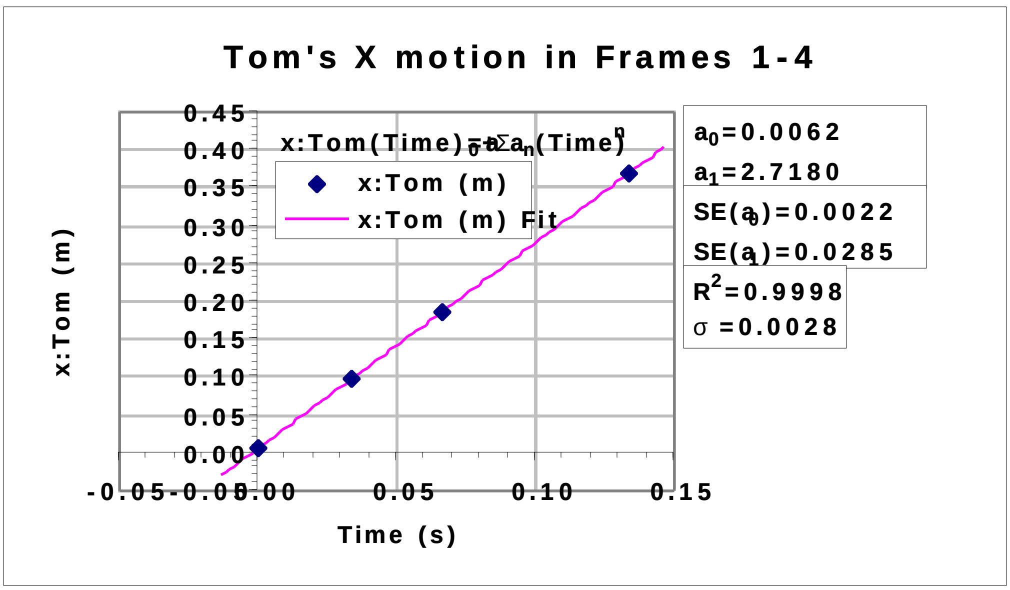
Movie 3: Data Points; Tom and Spike Collision

Fr #	Time (s)	x:Tom (m)	y:Tom (m)	x:Spike (m)	y:Spike (m)	y:Tom cofm(m)	
1	0.0000	0.006	0.134	0.517	0.213		Before
2	0.0333	0.099	0.145	0.520	0.210		Collision
3	0.0667	0.185	0.139	0.520	0.213		
4	0.1333	0.369	0.139	0.514	0.213	0.173	
5	0.2000	0.486	0.142	0.551	0.250	0.199	During
6	0.2667	0.619	0.148	0.608	0.293	0.210	Collision
7	0.3000	0.656	0.156	0.651	0.324	0.222	
8	0.4000	0.685	0.298	0.631	0.384	0.315	After
9	0.4333	0.656	0.315	0.616	0.384	0.335	Collision

We estimated the mass of Tom to be 12 lb. and the mass of Spike to be 115 lb. based on information published on a Bulldog stud. Since Spike is in contact with the ground during the collision we aren't able to measure momentum conservation. But, during the collision the upper half of Spikes body (estimated to have a mass of about 50 lb. or more) recoils and rises. Tom also rises. The mass data used in additional calculations is shown in the table below.

	lb	kg
m-Tom	12	5.5
m-Spike (1/2)	50	22.7
m-Spike all	115	52.3

Tom appears to be moving at a constant velocity in the first four frames before he comes into contact with the bulldog. We did a linear fit on these frames as shown in the graph that follows.



Tom's initial velocity in the x-direction is 2.71 m/s. We also found the after collision Tom and Spike both change their x-positions in a parabolic fashion, so we found their collision accelerations by doing a quadratic fit on each of their x vs. time data. Tom's acceleration came out to be -14.9 m/s^2 and Spike's was -9.2 m/s^2. We then multiplied each acceleration by the estimated mass of each animal to see if the mutual collision forces were approximately equal and opposite which is required by Newton's Third Law. We got the following results

$$F_{Tom} = (5.5\ kg)(-14.9\ m/s^2) = -81\ N$$

$$F_{Spike} = (50\ kg)(-9.2\ m/s^2) = -210\ N$$

We assumed from looking at the movies that only the front half of Spike's body was involved in the recoil. This looks like a violation of Newton's Third Law.

We also estimated the kinetic energy that Tom had before collision. This came out to be

$$E_{kin} = \tfrac{1}{2} m_{Tom} v^2 = \tfrac{1}{2}(5.5kg)(2.7^2) = 20J$$

Next we looked at the center of mass data for Tom and Spike, as they seem to rise up after the collision because Spikes hind legs are against a pillar. We wanted to see if Tom had enough kinetic energy to cause to potential energy increase after collision. This rise takes place between frames 4 and 9 and we calculated each rise as

$$h_{Tom} = (.335m - .173m) = .162m$$

$$h_{Spike} = (.384m - .213m) = .117m$$

The potential energy gain of the pair is given by $E_{pot} = m_{Tom} a_g h_{Tom} + m_{Spike} a_g h_{Spike}$. Using the same estimate for the masses as before we get E_{pot} = 45 J. This is more than two times the original kinetic energy of Tom.

Conclusions:

:Movie 1:

After analyzing the data we found the acceleration of the falling vase to be constant. We used a quadratic fit to find the acceleration. Since this was reasonably close to the accepted value we played with the data to find out what table height would give an acceleration of a_y = -9.8 m/s2. A reasonable table height of 35" gave the physically correct result for the vertical acceleration of the vase. The fall was realistic and the person who drew the cartoon seemed to understand physics.

Movie 2:

We found different results in movie two. Velocity was constant by means of calculations and by graphing. The velocity of the mouse was -1.2 m/s. Therefore the acceleration of the mouse equals zero. Because of the magic of cartoons Jerry was able to break the known laws of physics. This fall was faked.

Movie 3:

In this movie we determined that Newton's third law was violated as Spike experienced much more force than Tom during their collision. In viewing the movie we see the combined system had a final velocity of zero since Tom and Spike did not move away as one system. After taking data points and finding Tom's initial velocity we calculated his initial kinetic energy. The center of mass of both Tom and Spike rose as a result of the collision and it appears that the gravitational potential energy after the collision was more than two times the original kinetic energy. This is impossible unless Spike used his muscles to push against the floor and rise or unless Spike has an unreasonably small mass. Thus, Tom's influence on the motion of Spike is much greater than the laws of physics would allow. However, the collision would be less interesting if the cartoonist had obeyed the laws of physics.

Improvements and Errors:

The first thing that we could have improved on and had error on was accuracy of distance measurements or scaling on video point. Possible errors could have occurred in taking data points with a moving background.

There also could have been errors in our estimates of the masses of the animals since we had to use the average masses of a mouse, cat, and dog.

Sometimes objects in cartoons are not proportional to each other in size. For example Jerry looked unusually small compared to the milk bowl in movie two.

In conclusion, even if the masses and distances are not accurate there is no error in time, so velocity can be shown to be constant or not constant in each fall in the first two movies. Only one of the three events comes close to obeying the known laws of mechanics.

References:

Gartenhaus, Solomon. Physics, Basic Principles. Holt, Rinehart and Winston, Inc. New York. 1975.

Halliday, Resnick, Walker. Fundamentals of Physics. John Wiley & Sons, Inc. Canada. 1997.