Experiment 1: Uniform Acceleration

Kubilay Agi

UID: 304784519

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Lab Section 8 – Monday/Wednesday 11:30am

TA: Jordan Runco

Partner: Shannon Largman, Tian Dai
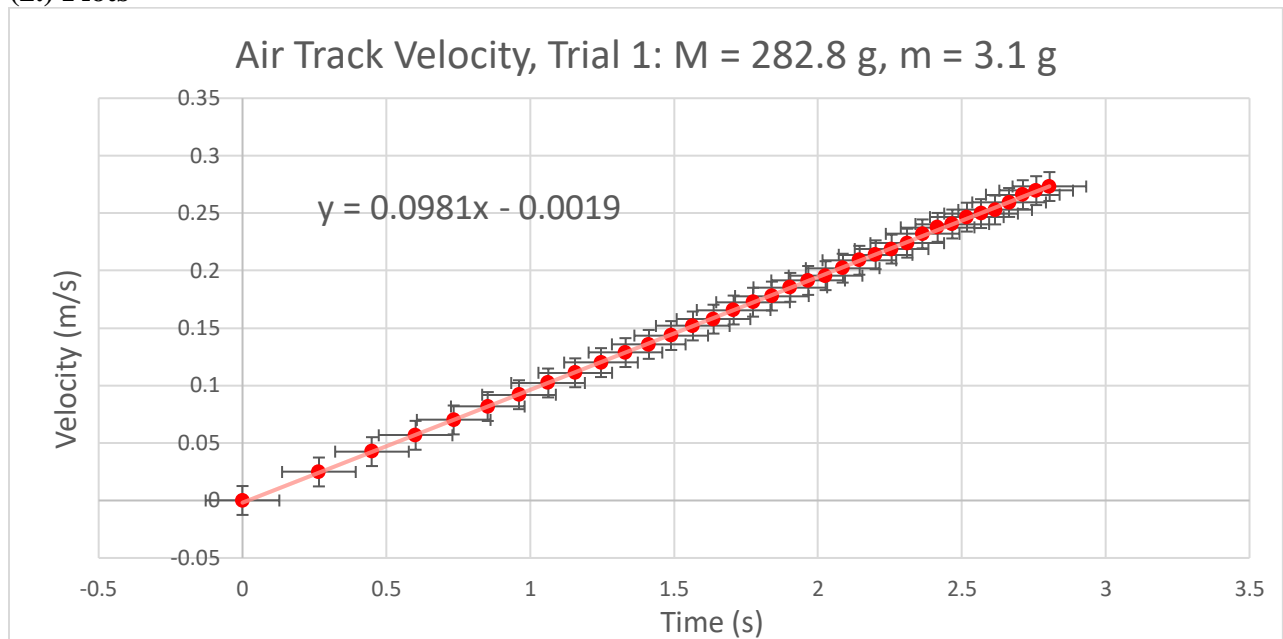
Worksheet

(2.) Plots

Figure 1: This is a plot of the velocity (m/s) of the glider against time (s). The slope of the trendline is the acceleration of the glider and has a value of $(0.0981 \pm 0.0002)\ m/s^2$. From the data, we deduce that the velocity increased by a constant factor per each unit of time. The glider originally had mass 182.2g but we attached masses of 50.1g and 50.5g to it.
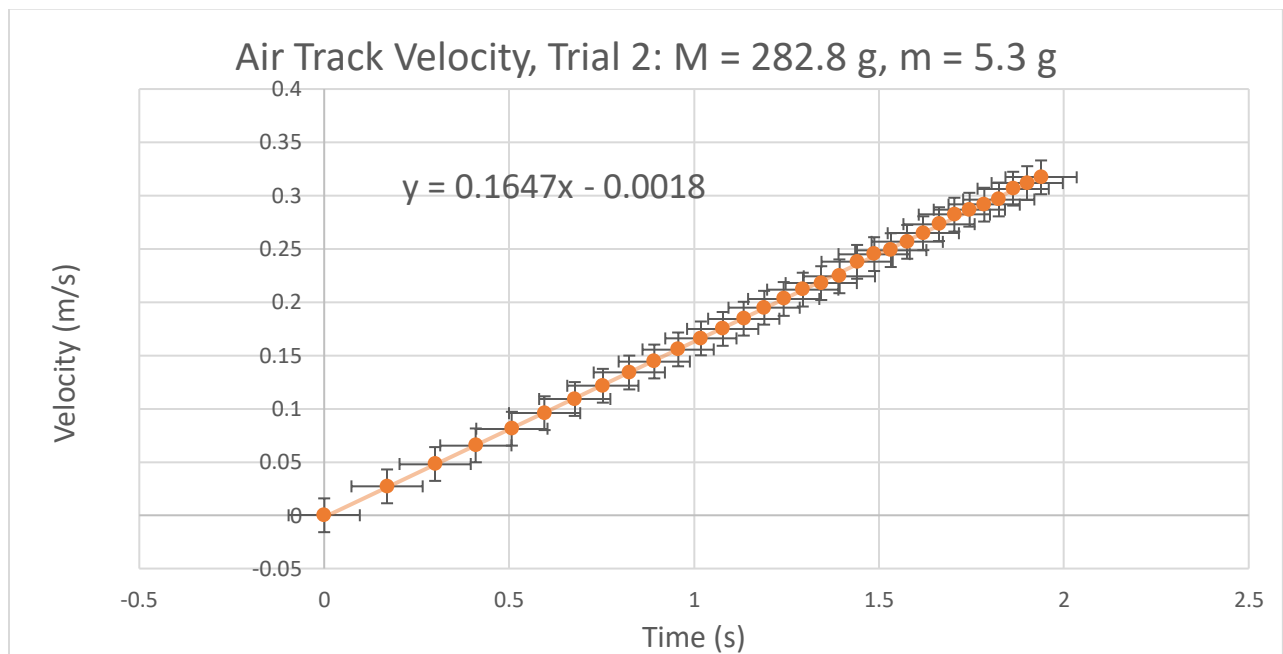

Figure 2: In this scenario, we attached a 5.3g mass to the end of the string, and the glider still weighed 282.8g. The slope of the trendline and acceleration of the glider is $(0.1647 \pm 0.0005)\ m/s^2$.

Air Track Velocity, Trial 3: M = 282.8 g, m = 19.3 g
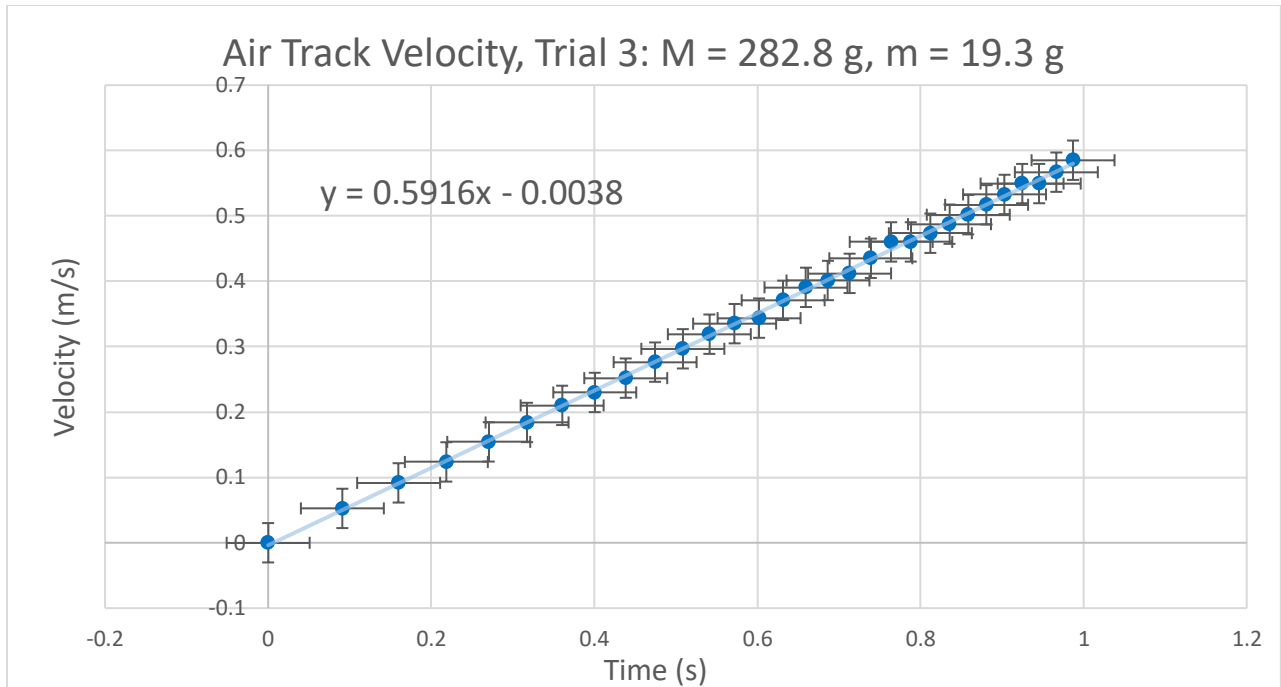
$y = 0.5916x - 0.0038$

Velocity (m/s)

Time (s)

Figure 3: For the third trial, we attached a mass of 19.3g to the glider, which has the same weight of 282.8g. The slope of the trendline and the acceleration of the glider is $(0.5916 \pm 0.0028)\ m/s^2$.

Air Track Velocity, Trial 4: M = 282.8 g, m = 36.1 g

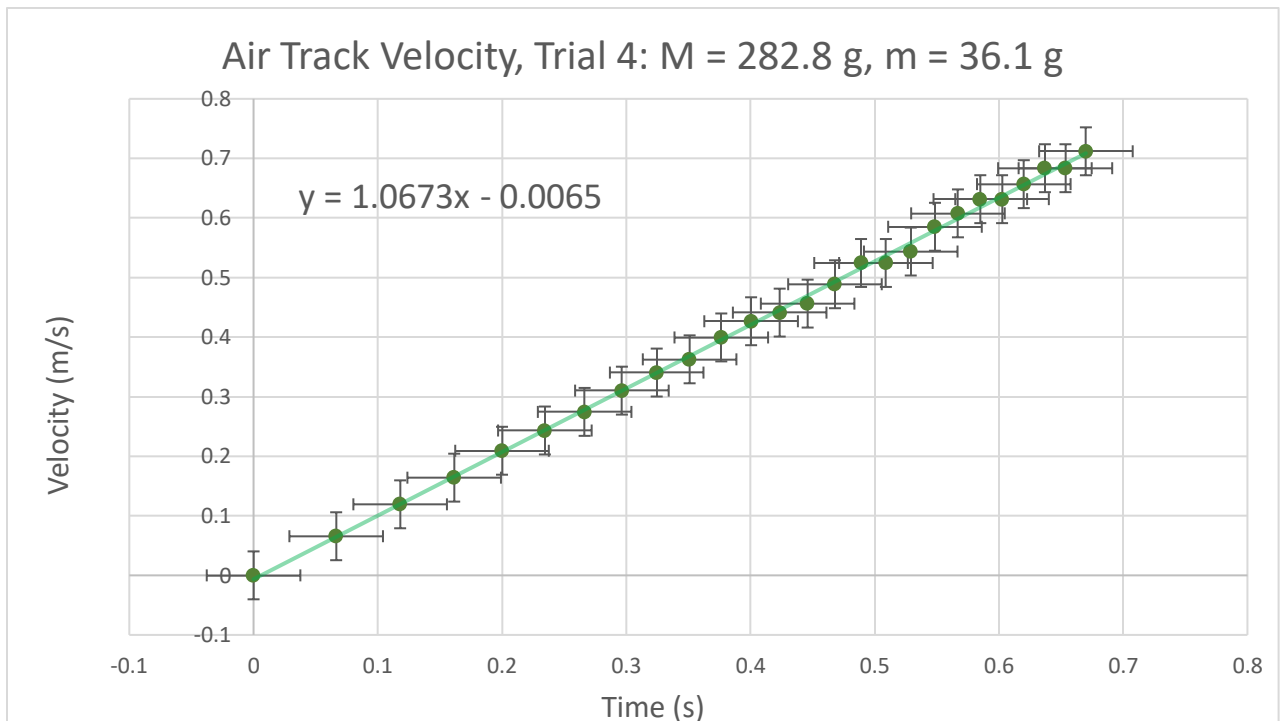$y = 1.0673x - 0.0065$

Velocity (m/s)

Time (s)

Figure 4: The fourth trial was the last trial in which we used the glider of mass 282.8g. We attached a mass of 36.1g to the end of the string attached to the glider. The slope of the trendline and the acceleration of the glider is $(1.067 \pm 0.0077)\ m/s^2$
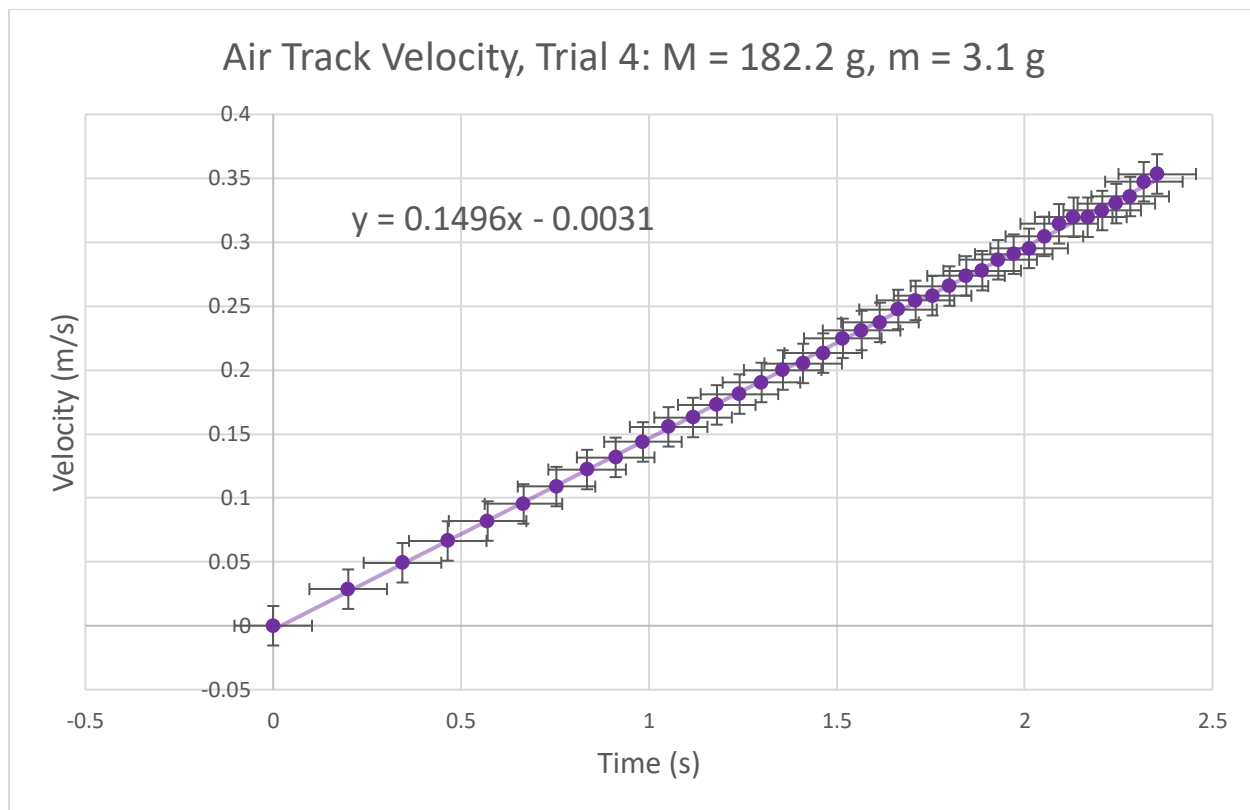
Figure 5: In this scenario, we changed the weight of glider by taking the masses of 50.1g and 50.5g off of the glider. We attached the same 3.1g mass to the end of the string as in Trial 1. The slope of the trendline and acceleration of the glider is $(0.1496 \pm 0.0005) \; m/s^2$.

All five plots show that the velocity of the glider increased as time went on. This is because the glider was acted on by the tension force generated from the hanging mass' acceleration due to gravity. The pulley allowed us to translate the downward force acting on the hanging mass into a horizontal force acting on the glider.

(3.) Data Table

Trial	Hanging Mass $m_{best} \pm \partial m \; (g)$	Glider Mass $M_{best} \pm \partial M \; (g)$	Fit Acceleration $a_{fit} \; (m/s^2)$	Predicted Acceleration $a_{predict} \; (m/s^2)$
1	3.1 ± 0.2	282.8 ± 0.35	0.0981 ± 0.0002	0.11 ± 0.033
2	5.3 ± 0.2	282.8 ± 0.35	0.1647 ± 0.0005	0.18 ± 0.033
3	19.3 ± 0.2	282.8 ± 0.35	0.5916 ± 0.0028	0.626 ± 0.030
4	36.1 ± 0.2	282.8 ± 0.35	1.067 ± 0.0077	1.11 ± 0.027
5	3.1 ± 0.2	182.2 ± 0.2	0.1496 ± 0.0005	0.16 ± 0.052

Figure 6: This table shows the relation between each combination of hanging mass and glider mass with the fit acceleration the predicted acceleration (calculated with equation 1.1 in section 4). The uncertainty of our measurement of mass was 0.2g. For trials 1-4, the uncertainty is higher because we attached two masses to the glider, each with an uncertainty of 0.2g. Using equation ii.22 from the lab manual, the resulting uncertainty is 0.35g.

(4.) Derivations

We are asked to derive equation 1.1 from the lab manual. We notice that there are two separate objects to consider in this scenario: the glider and the hanging mass. The forces acting on the glider are the horizontal force of tension from the string pulling it along the track. There is also the force of gravity pushing downwards, which is cancelled out by the upward force of the air flow from the track. We make the assumption that the track provides us with a frictionless surface for the glider to move on. We also disregard the force of air resistance in this experiment. In the case of the hanging mass, there is a force of tension pulling the mass upward as well as the force of gravity pulling it downward. We apply Newton's second law to both objects.

For the glider:
$$\sum F_{glider} = F_{tension} + F_{gravity} + F_{air} = F_{tension}$$

$$F_{tension} = Ma$$

For the hanging mass:
$$\sum F_{hanging} = F_{gravity} - F_{tension} = ma$$

By substituting the equation for the glider into the equation of the hanging mass, we get the following equation, which we will manipulate in order to attain equation 1.1 as our final result.

$$F_{gravity} - Ma = ma$$

$$F_{gravity} = mg = ma + Ma$$

$$mg = a(m + M)$$

Now we arrive at equation 1.1:
$$a = \frac{gm}{m + M}$$

To derive an equation for the propagation of uncertainties, we start with equation ii.14 from the lab manual and substitute in the values M, m and a.

$$\partial a = \sqrt{\left(\frac{\partial a}{\partial m} \partial m\right)^2 + \left(\frac{\partial a}{\partial M} \partial M\right)^2}$$

We solve for the partial derivatives for each of the terms under the radical.

$$\frac{\partial a}{\partial M} = \frac{-gm}{(m+M)^2}$$

$$\frac{\partial a}{\partial m} = \frac{gm}{(m+M)^2}$$

After plugging these results back into our equation, we simplify it down to this form:

$$\partial a = \left| \frac{g_{best}}{(m_{best}+M_{best})^2} \right| \sqrt{(M_{best}*\partial m)^2 + (m_{best}+\partial M)^2}$$

Equation 1.1 and the derived equation to calculate propagation of uncertainties will be used to calculate the predicted acceleration values for section 3.

(5.) Conclusion

For this experiment, we measured the effect of mass on the acceleration of a glider on an air track. Measurements were taken for five different combinations of hanging masses and glider masses. The position of the glider along the track with respect to time was recorded. This data was used in equation 1.3 from the lab manual to calculate the velocity of the glider. The velocities are plotted against time in section 2. The slope of each trendline is equal to the fit acceleration of the glider during each individual trial. The nonzero intercepts in each plot indicate that the glider had a small velocity at the beginning of the trial. This can be attributed to human error when releasing the glider; the hand of the person may have gotten in the way at the beginning of the trial.

The predicted acceleration calculated with equation 1.1 is always slightly higher than the fit acceleration from our model. This makes sense because the predicted acceleration assumes an ideal environment, which is not the case when we conducted our experiment. For example, it was difficult to make the track completely level. The glider would begin to move after being placed on the track at rest in some sections along the track, but not in others. A portion of the hanging masses' potential energy may have been lost due to environmental factors such as air resistance during its fall. There are several other possible sources of error in this experiment as well.

For example, one possible source of error is friction. The pulley was not necessarily frictionless against its axis as it spun. If it was not sufficiently lubricated, the friction between the pieces of it could lead to friction. In addition, the string would begin to rub against the side of the hole which it was threaded through to connect to the pulley as the glider approached the end of the track.

Preventing friction and taking care to minimize user error are two fields where improvements can be made to produce more accurate results from this experiment. We can use lubricant for the spinning pulley and the for string where it rubs against the apparatus. There is little that can be done about air resistance acting on the falling mass and the glider unless we are able to perform the experiment in a vacuum. For user error, we can use a mechanical release mechanism so that

we do not get in the way of the glider as we are releasing it. This would eliminate any error present in the initial data points affected by releasing the glider inconsistently. Finally, if the mass was left swinging and not steadied before the trial, this may also affect the data because it is not consistent across all trials.

With these improvements to the experiment, it is likely that the resulting fit acceleration would be closer to the predicted acceleration.
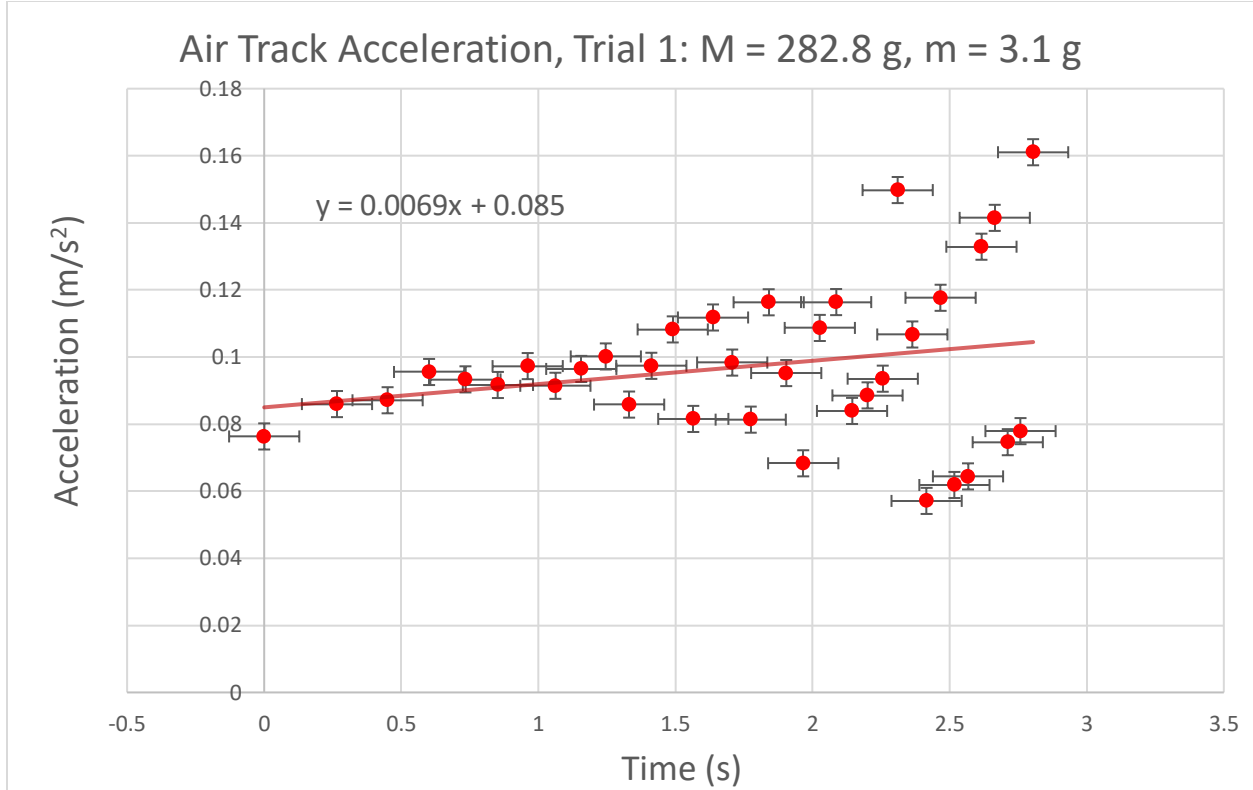
(6.) Extra Credit

Figure 7: This is a plot of the glider's acceleration with respect to time. The data is taken from trial 1 which used a glider of mass 282.8g and a hanging mass of 3.1g. Until about one second, the data points appear to converge on a single value, but they become more inconsistent as time goes on.

The average value of acceleration across all the data points is 0.0971 m/s^2. We have $N = 36$ data points and standard deviation $\sigma_a = 0.023$ m/s^2. From equation ii.1.6, we can calculate the uncertainty of the mean value.

$$\partial a = \frac{\sigma_a}{\sqrt{N}}$$

Plugging our values of N and σ_a into equation ii.1.6, we find that the uncertainty of the acceleration has a value of 0.0038. Combining the value of acceleration with its uncertainty, we have the resulting value of (0.0971 ± 0.023) m/s^2. The fit acceleration for this trial was $(0.0981 \pm$

0.0002) m/s^2. Ideally the data points would form a horizontal line since acceleration should be constant. The fit acceleration is the better representation of the acceleration because it is closer to value of the predicted acceleration, which is the acceleration in the ideal case. It also has a lower value of uncertainty. The reason for the noise in Figure 7 is likely due to environmental factors such as friction with the pulley. If the pulley was sticky in a certain position and then slipped quickly back into rotation, that would explain the alternation of the data points across the trendline.

Presentation Mini-Report – Supermassive Black holes

Black holes, first discovered in the 20th century, are an anomaly in the scientific world. They are objects that cannot be seen, but they have an immense gravitational force and absorb everything around themselves without allowing anything to escape. Black holes are known to exist in two categories: those that are 10 times as massive as our Sun and those that are billions of times more massive than our sun.[1] A black hole of the second type is referred to as a supermassive black hole (SMBH). Supermassive black holes reside at the center of nearly every galaxy.

It is theorized that there is a fundamental relationship between SMBHs and their host galaxies. Thus, research on SMBHs is important because it can lead to answers about how galaxies were formed and the fate of each galaxy as it grows older. It also provides insight into the dynamics between galaxies that collide with each other. Because our Milky Way galaxy is on a collision course with Andromeda galaxy, it would be interesting to develop a prediction of the outcome. A SMBH's behavior can also reveal properties of black holes in the general case, including the smaller ones which are more challenging to locate in the universe.

Part of the reason that SMBHs are easier to spot is because they fuel objects referred to as quasi-stellar objects (quasars). Quasars emit jets of energy which causes the quasar to shine brighter than their own host galaxy.[2] The existence of quasars is part of the reason why physicists were able to deduce that galaxies had SMBHs at their center. only a black hole of tremendous size could release enough energy to outshine its own galaxy.[3] This precedent suggests that black holes may also be behind other phenomena observed in the universe.

Since the 1990s, it has been observed that the mass of the SMBH is directly proportional to the luminosity of the bulge at the center of its host galaxy. In addition, a more recent finding shows that the mass of the SMBH is proportional to the stellar velocity dispersion of the galactic bulge, which is the average speed of all objects surrounding the black hole.[4] The SMBH's gravitational force is directly proportional to its mass and accelerates the stars and other objects toward itself, absorbing the ones that stray too close and propelling the others away like a slingshot. There have also been connections drawn between the stellar mass of the galactic bulge and the mass of the SMBH. However, the correlation between luminosity and SMBH mass is stronger.[5] Nonetheless, the increasing number of connections uncovered between galaxies black holes raises the likelihood that there are deeper ties between the existence of the two. Perhaps the two entities are dependent on each other to survive or even to exist.

Galaxies and SMBHs also grow in a similar fashion. An increase in mass for both of them is done through accretion of the particles surrounding them or through the merging of two entities.[1]

In a merging between two galaxies, the two SMBHs will circle around each other and eventually meet in the middle due to gravitational attraction.[2] When they meet, they combine into a larger SMBH with proportional mass. There is also speculation that a quasar's activity lines up with the rate of star creation. If this turns out to be true, the evidence of ties between SMBHs and galaxies become stronger.

Although we have already observed several connections between supermassive black holes and their host, there are likely still many more discoveries to be made. One possible next step for this field of research is to uncover the transformation undergone by the matter and energy absorbed by the blackhole. This is a nontrivial task, however, as it is impossible to escape the black hole once one crosses the event horizon. Better understanding of black holes would also provide a way to begin researching the existence of wormholes, entities which only exist in science fiction as far as we know. Research on black holes offers a promising future and could lead to insights on both the nature of black holes themselves and about the history and future of our own galaxy.

Word count: 696

Bibliography

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