International Baccelurate: Extended Essay

Investigation of Effects of Longtidunal Position of Center of Gravity of a Paper Aeroplane on Its' Horizontal Displacement.

Onur POLAT
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Physics

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Abstract

This essay studies the change in behavior of a glider during flight with variying horizontal displacement of its center of gravity. Even if it looks most of the humans like a child's play, it involves all of the flight dynamics, which also apply for modern, high technology aeroplanes. Essay is centered around the question "How does the horizontal displacement of a glider varies with changing horizontal placement of center of gravity of the glider?" Troughout the essay, the question is evaluated from two aspects. Firstly, what is the cause of the change in behavior? Under that aspect, causes of the behavior is explored and proved with data collected and processed from the experiment. Secondly, what are the implications of this change? Under this aspect, effect of the causes on the glider was discussed in order to explain how they cause the change in behavior of the glider. At the beginning, a rigorous research on flight dynamics was made. Afterwards it have been decided to use a paper glider launched by a rubber band. A cotton string with a paperclip is used to pinpoint the location of center of gravity and sytraphor plates on a string were used as wind detectors. Fifty trials in total were performed and collected data is processed to obtain a result. A graph was drawn and function relating them was found. Later on, implications of this function and its' strengths and weaknesses were discussed. Based on that discussion on function dsplayed in the graph, standard deviation and error values, conclusiveness of the result was discussed. Moreover, discussions made under two aspects in which central question was evaluated, were put into coherence check with theoritical expectations. In the end, further questions and research areas emerging from the conclusion was discussed with proper explanations.

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Introduction

Scope of the Work

In daily life, making a paper glider and throwing it seemed to be a child's play. It is not seen as sophisticated as it really is. The child's play become a frusturating problem of an engineer when it analysed in depth.

Intention of this essay is to explain flight dynamics behind the movement of the glider during flight and its' effect on horizontal displacement of the glider. Focus is the effects of changing horizontal placement of center of gravity of the glider relative to an imaginary line connectig its' wingtips. It includes gathering information about horizontal displacement of the glider, its behaviors during the flight, placement of its' center of gravity; then connecting all of these vatiables to each other according to relevant scientific theories and laws; In the end, constructing a conclusion based on these datas, which was evaluated by means of conclusiveness. It must have been taken into consideration that there are further areas for additional reserch were arised from this work.

Background Information

Forces Affecting on Planes[1]

Like every object investigated in mechanics, there is a free body diagram for a plane. On the diagram, four forces are shown being exerted on an aeroplane. They are:

1. Lift
2. Gravitational Force (Weight)
3. Thrust
4. Drag

1.Lift

Lift is the force acting upwards on the plane. Lift is the force which opposes the downwards pull of the gravitational force and making flying aircrafts possible. Lift is created via wings of the aircraft, which has a specific cross sectional profile, more commonly called as "wing profile" For subsonic aircrafts, wing profile looks like a "raindrop" shape cut in half. I put a diagram representing the most used wing profile(Clark – y Profile) below in order to clarify it.

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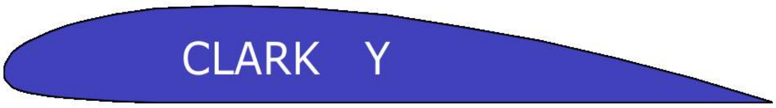
Diagram 1(Clark – Y airfoil)



According to bernolli's principles[1] about fluid dynamics, faster a fluid flows, lesser the pressure it applies to the surfaces surrounding it. Wing profile works with this principle. Flow over the profie is faster than flow at bottom, causing a force of pressure to be applied to the wings, directerd upwards, which causes lift.

2.Weight

Another force acting on plane is weight. Every mass is affected from gravitational interactions, so the aircraft. Earth pulls the aircraft to its' center of gravity with a force of 9.81 N per kilogram. We take this force as acting downwards, at opposite direction of lift. In order to achieve a stable altitude, weight and lift must be equal, resulting zero net force acting on the body.

3.Drag

Every moving object in some media (not in vaccum or interstellar space) faces with frictional forces due to the totally elastic colisions between atoms of the medium and object. During the flight, frictional force affects on aircraft which is at the opposite direction of its' movement relative to the medium. Without a force applied at the direction of movement, kinetic energy of the plane will eventually deplete, reducing its' speed, inevitably causing a fall. In order to counteract kinetic energy loss due to friction, thrust is applied on aircraft. In my experiment, a paper aeroplane lacking an engine (technically a glider) will be used. Without thrust, it will eventually land on the ground, after a short time on air.

4.Thrust

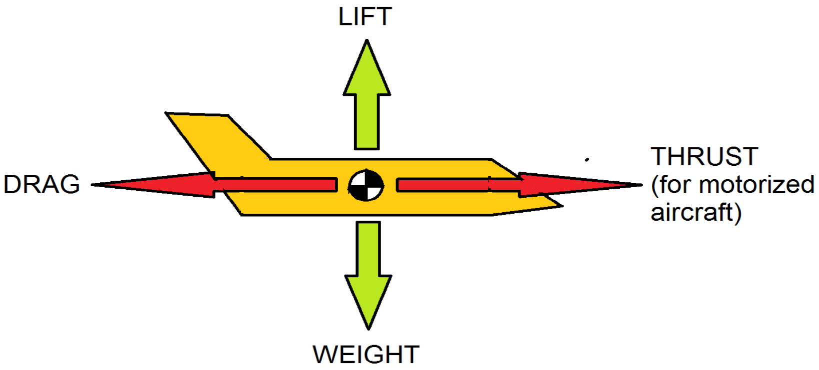
Thrust is the force which makes the plane to propagate in air. It works antoganistically with drag, counteracting its' effects. It can be either provided by an engine mounted on aircraft(on most occasions) or from an external source as in gliders and paper aeroplanes. For gliders, lack of thrust generating engines means that they are going to lose their energy, thus lift, therefore descend gradually and eventually land. In my experiment, I am going to use a paper aeroplane

1 Fishbane, Paul M., Stephen Gasiorowicz, and Stephen T. Thornton. "Applications of Bernoulli's Equation." Physics for Scientists and Engineers. Upper Saddle River, NJ: Prentice Hall, 1996. 448.

launched by a rubber band, which gains kinetic energy once in launch from elastic potential energy of the rubber band.

Four fundamental forces of the flight dynamics are two binary opposites as weight – lift and drag – thrust. As in Newtonian physics, they are thought to be acting around center of gravity of the plane. In order to sustain a stable flight both horizontally and vertically, net torque around the center of gravity must be zero. Diagram below shows how they act together on a plane.

Diagram 2 (Fundamental Forces acting on a plane around its' center of gravity)

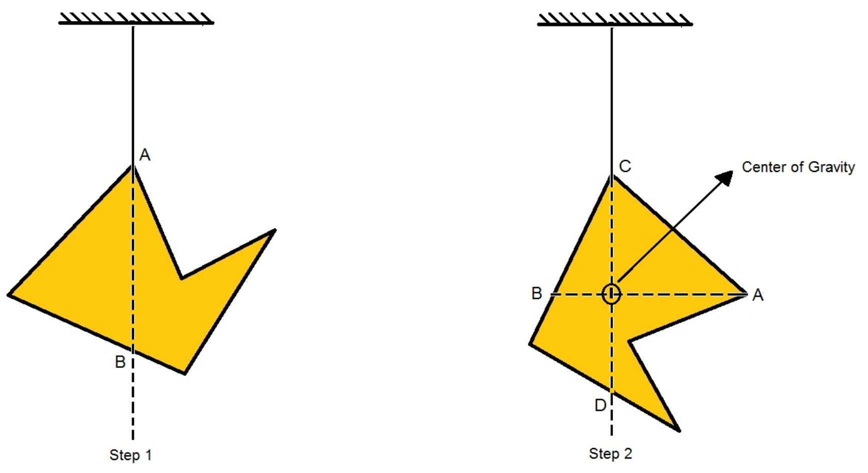


Center of Gravity[2]

Every object in the universe, independent from their form and uniformity has a center of gravity (or center of mass), where forms a pivot point which the net torque affecting on the plane due to the gravity becomes zero.

For a paper aeroplane, I thought that it can be determined easily with a paperclip, string and a ruler. When an object is hung with a rope, it remains in equilibrium, when the net torque acting on it is zero. When the object reaches the equilibrium, an imaginary extention from the string which it was hung passes from the center of gravity. By hanging it from two different points on the body, intersection point of the imaginary lines will give the longtidual position of the center of gravity. It also shows that aeroplane is symetric by means of mass. If the imaginary line connecting the wingtips is parallel to the ground, than plane is in horizontal equilibrium. I added a diagram showing the system used to determine center of gravity of plane and its' lateral symmetry of mass.

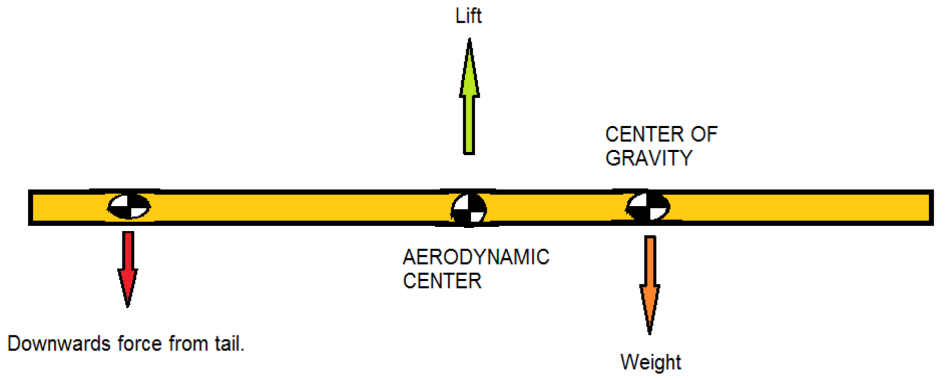
Diagram 3 (Diagram showing the main principles of the system used to pinpoint the horizontal placement of center of gravity)



Aerodynamic Center[3]

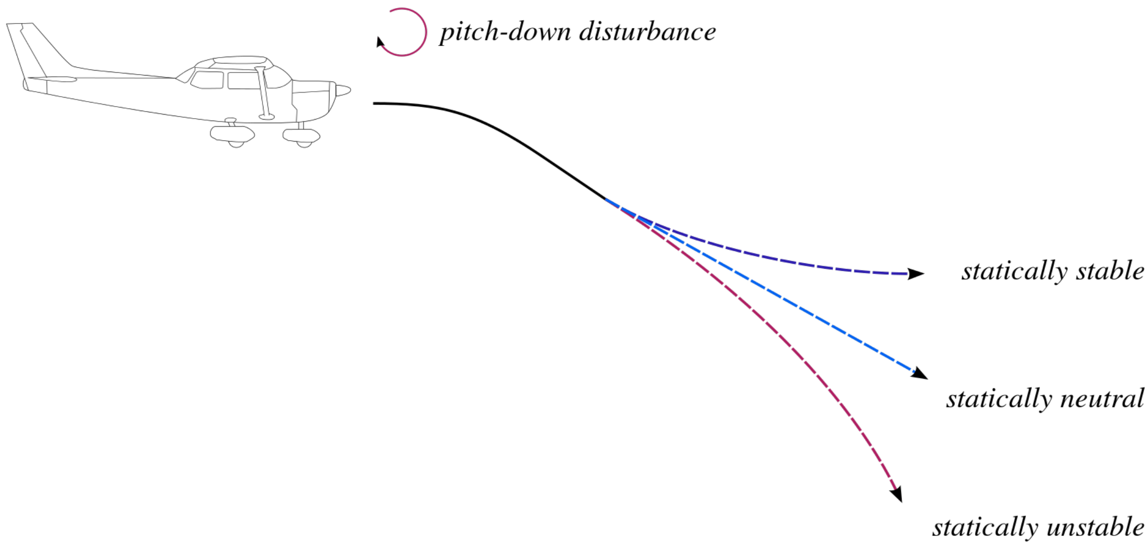
Like the center of gravity, there is a point on the plane where net torque created by the lift around that point is zero. This point is called as “aerodynamic center.” Relative position of the aerodynamic center to center of gravity determines the stability of the plane. Theoritically, If a plane has its' aerodynamic center behind the center of gravity, it is said to be statically stable. This is because counteractng moment vectors. In order to understand the concept, I thought the plane as a linear rod and placed lift and weight forces, aerodynamic center(where lift was thought to be acting on that point, as in the case of weight) and center of gravity on it. Diagram 4 below represents this model.

Diagram 4(Vertical forces acting on a plane, with center of gravity and aerodynamic center)



Stable planes forms negative feedback mechanism to any change made on the plane during the flight. However, If center of gravity falls behind the aerodynamic center, plane becomes unstable, form negative feedback to the changes made during the flight, like pitching down. Three phases of stabilty is shown in diagram below.

Diagram 5 [4](How does planes with different stability properties will tend to behave after a pitch down disturbance)



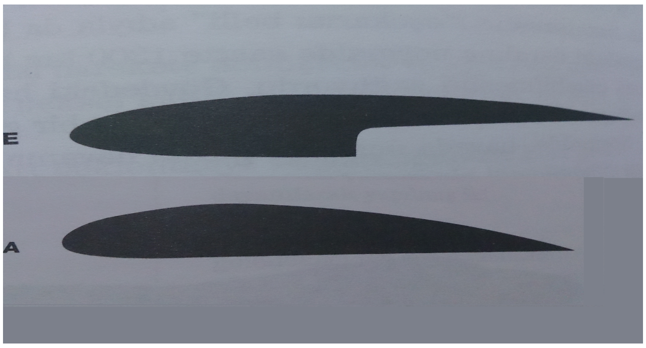
For planes with cambered or thin aerofoils, placement of the aerodynamic center is approximately 1/4th length of the mean aerodynamic chord from the attack side of the areofoil.

Kline – Fogleman Aerofoil[1]

This type of aerofoils are different from “clark-y” aerofoils. Their upper surface is not smooth. Instead, they have a “step” on the airfoil. The difference between clark – y profile and Kline - Fogleman profile can be seen in picture below.

Picture (Kline-Fogleman Aerofoil is “E”; Clark – y is “A”.)[1]

(in this picture, Kline - Fogleman airfoil was placed upside down. Its' gap can either be on upper or lower surfaces of airfoil)



I observed that almost all paper aeroplane designs has variations of kline – fogleman profile. It has direct effects on capabilities of aeroplane, since aircraft becomes more resistant to stalling and reduces friction. It extends range of the paper aeroplane, Aeroplane with this type of aerofoil is more resistant to stall, can achieve higher angle of attack without any anomaly. Due to this property, I deceded to use a model which has a kline fogleman profile at bottom of the wing. By that way, aircraft will not be effected much from stalling conditions, minimizing errors in the result.

Research Question: How does relative position of center of gravity to wingtips of a paper aeroplane affects its' flight distance? Measured by measuring the horizontal displacement of the plane during its' flight.

Hypothesis: When center of gravity moves ahead of the datum passing trough the wingtips of the paper aeroplane, range of the plane the plane will increase, reach a maximum, then followed by a decrease due to net torque affecting on plane downwards from nose area. When center of gravity moves behind the wingtips, it will result a sharp decrease in range due to stalling of the plane just after its' launch Stalling will be caused by net torque acting on the plane from tail section.

Independent Variable: Relative placement of the center of gravity of a plane to its' wingtips.

Dependent Variable: The horizontal displacement of the plane during its' flight.

Controlled Variables

Controlled Variable	Why was it controlled	How did it control
Temperature	Temperature of air determines its' density and pressure. Lift crated by the wing is connected to these varibles, so at different temperatures, wings will create different lift at the same airspeed.	By placing a thermometer in the experiment hall. Thermometer will be read beforehand and the value on it will be recorded.
Humidity	With increasing humidity, rigidity and durabilty of the paper decreases. This results in irreversible chages at body of the plane, affecting its' aerodynamic properties thus affecting its' flight distance.	Humidity levels in the hall will be measured by a hygrometer. For experiment humidity below % 40 must be present.
Air Pressure	Pressure is a factor which determining density of the air, thus lift created by the wings at a certain airspeed. Therefore it is a factor determining the flight distance.	An analog barometer will be used to measure pressure in the hall.
Paper Type	Paper type determines rigidity and durability of the plane, friction affecting on it, planes' mass and position of center of the gravity. All these factors affects the flight distance.	An A4 size 10.03g glossy paper will be used in the construction of the experiment plane.
Plane Shape	It is a main factor affecting static and dynamic properties of aircraft.	Only one plane will be used during the experiment.

Wind Speed	Wind speed determines the flight direction and relative airspeed of the plane, therefore its' flight distance.	It wil be measured by using an analog wind detector.(See Diagram 6)
Launch Speed	Launch speed determines the kinetic energy of the plane which directly affects its' flight distance.	The plane will be launched by a catapult made by a rubber band, always tensed to a certain distance from resting position.
Launch Angle	Firstly, it causes plane to elevate in the launch, increasing its' flight distance. Secondly, too high angles will cause plane to stall and drop, which will reduce flight distance significantly.	The plane will be launced from a plane which is horizontal to the surface plane in the experiment hall with a rubber band catapult.
Launch Height	It determines how much potential energy that plane can convert into kinetic energy during the flight, thus its' flight distance.	All of the launches will be performed from a plane which is 22.4 cm above the ground.

Material List

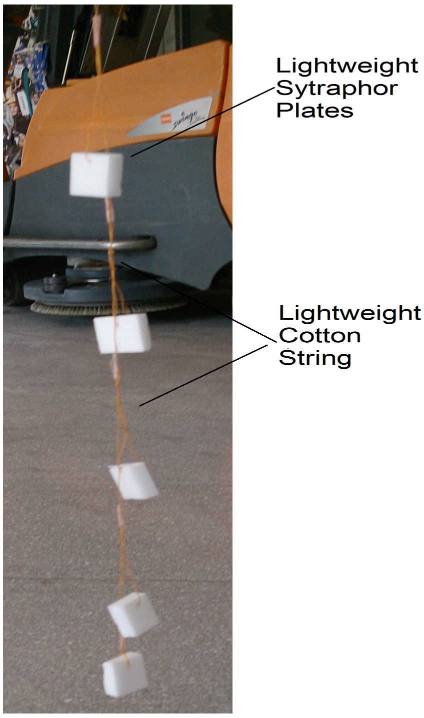
1. Glossy paper. (A4 size, x1, 140 g)
2. Scissor.
3. Two sided selotape.
4. Paperclip.(x4)
5. Meter tape. (500.0 cm)
6. Rubber band. (10.0 cm)
7. String.
8. Thermometer. (+/- 0.1 ^{o}C)
9. Hygrometer. (+/- 0.05 %)
10. Barometer. (+/- 0.05mb)
11. Sytraphor plates.

Procedures

1. Tie the string to the paperclip. (Diagram 3)
2. Attach paperclip to the plane to a place on its' body which you think close to its' center of gravity. When plane reaches equilibrium, draw extension (imaginary) lines of the string on the plane body.(Diagram 3)
3. Repeat step 2 for two different points on the body of the plane.(Diagram 3)
4. Place thermometer, hygrometer, barometer and the analog wind detector in the experiment hall. Record the readings on them and observe their movements.

Analog wing detector is not capable of measuring the speed of the wind. However it is able to indicate presence of an air current even if it is so slow that imposibble to be felt by a human being. It manages this property with extermely light sytraphor plates with great surface area relative to its' weight attached to a light cotton string. Diagram below shows the structure of the wind detector.

Diagram 6

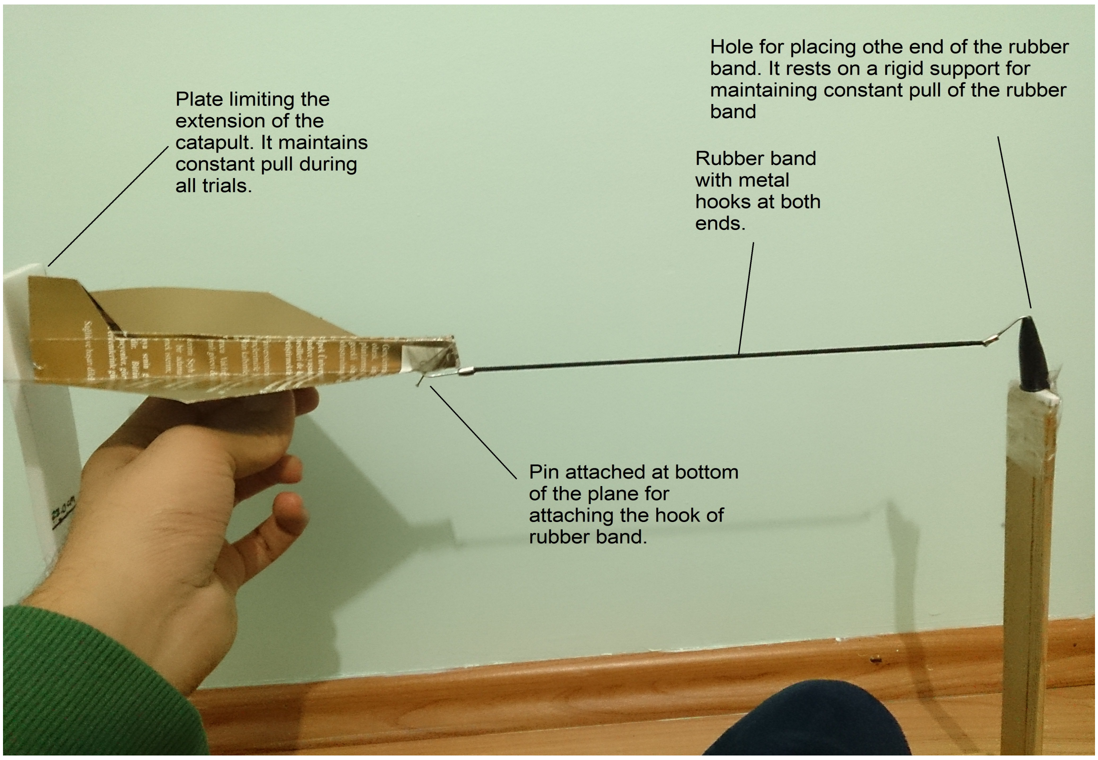


5. Place catapult made up of rubber band horizontally and 0.0 cm above the ground.
6. Pull the plane up to back limit, then release it.

7. Pinpoint the exact location of the tail tip of the plane where it landed.
8. Measure the linear distance between point defined in seventh step and front end of the catapult. Note the results.
9. Launch paper plane again with the catapult with respect to the step six. Then apply the procedures defined at steps seven and eight.(x4)
10. Change the longtidual placement of paperclips on the plane.
11. Determine new position of center of gravity according to steps 2 and 3 respectively.
12. Repeat steps 6,7,8,9,10 and 11 again, for nine times more.
13. Draw relative position of center of gravity to the chord connecting wingtips versus flight distance graph.
14. Deduce an expression from the best fit (it does not have to be a line) of the data set indicating the relation of center of gravity and its relative displacement from chord connecting the wingtips of the plane.

<u>Pictures and Diagrams of Experimental Set Up</u>

Picture 1(Catapult with Aeroplane)



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Data Collection and Processing

The experiment was conducted accotding to the procedures indicated above. Constant variables of the experiment are shown in Table 1(Constant Variables) in appendix. Raw datas were collected and recorded, shown in the appendix as “Table 2(Raw Data Table)”.

At first, for all dependent variable datas gathered from conducted experiment, a mean value was calcuated. For the five data entries of the vertical distance between center of gravity and line connecting the wingtips of the plane of + 2.6 cm, mean value was calculated as:

(531.7 + 696.8 + 666.2 + 504.7 + 530.4) / 5 = 586.0 cm (+/- 0.174%)

Secondly, variance values for each entry for the column of “Flight distance” in Table 1 was calculated. For the first five entries of column corresponding to vertical distance between center of gravity and line connecting the wingtips of the plane of +2.6 cm in the column, variance value is calculated as:

$$(586.0 - 531.7)^2 + (586.0 - 696.8)^2 + (586.0 - 666.2)^2 + (586.0 - 504.7)^2 + (586.0 - 530.4)^2 = 7839.6 \text{ cm}^2$$

In the third place, standard deviation values were calculated, based on the variance in previous step. For the same entries, standard deviation is calculated as:

$$(\mathrm{Var}(x))^{½} = (7839.6)^{1/2} = 88.5 \text{ cm}$$

Afterwards, Table 2, processed data table of the experiment investigating the relationship Vertical distance between center of gravity and line connecting the wingtips of the plane and flight distance of the plane, was shown in appendix as Table 3(Processed Data Table) .

Ultimately, graph of mean flight distance of paper aeroplane versus position of center of gravty relative to the line connecting the wingtips of the paper aeroplane (Graph 1) was drawn, in order to show the variation in flight distance with changing position of the center of gravity.

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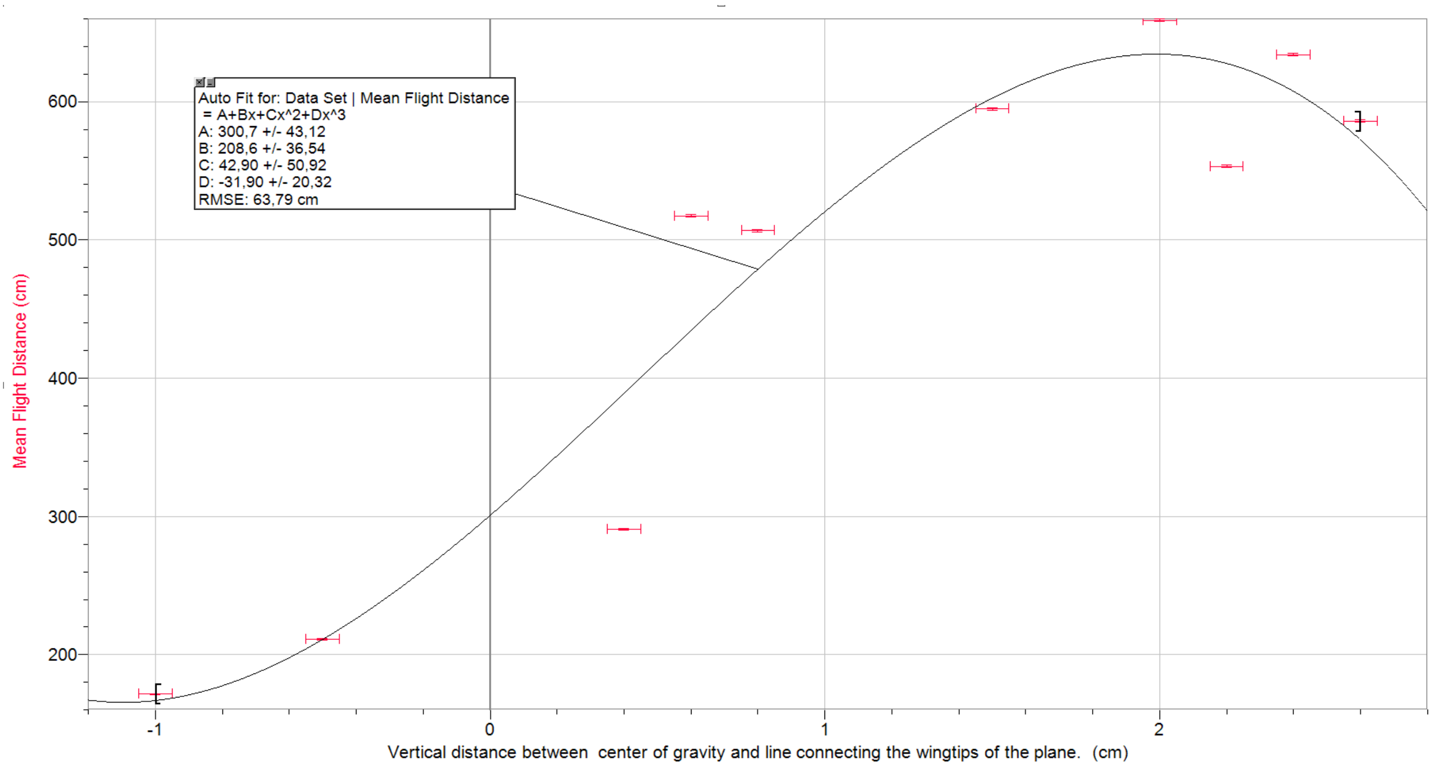
Graph 1(graph of mean horizontal displacement of paper aeroplane versus position of center of gravty relative to the line connecting the wingtips of the paper aeroplane)



According to the graph, there was not a linear relationship between horizontal displacement between center of gravity and line connecting the wingtips of the plane. Instead, there was a relationship which can be represented with a third – degree equation. Therefore no worst fit lines can be drawn.

$$y = -31.9(X^3) + 42.9(X^2) + 208.6(X) + 300.7$$

It is representation of a function defined from horizontal displacement from imaginary chord connecting wingtips of the plane to the range of the paper aeroplane. So when we put horizontal displacement of center of gravity relative to the chord connecting the wingtips of the aeroplane in the place of “X” in the function above, we will obtain a y value corresponding to it,which was a theoritical value of the horizontal displacement of paper aeroplane. Hence function above is a general result about effects of placement of center of gravity relative to the chord connecting the wingtips on the range of the aeroplane.

Conclusion and Evaluation

Third degree result indicates an optimum range of horizontal displacement between center of gravity and line connecting the wingtips of the plane. Therefore both overmovement or undermovement of horizontal position of center of gravity results in a decrease in flight range.

The “crashing” part of the graph corresponding between 0.6 and 0.4 values on x axis indicates a limit for the plane. Datas both above and below these points have a connection among themselves, whereas they do not look like related much as a whole. This is related to longtidual statistic stability phases. As in diagram 5, according to the phase of longtidual statistic stability of the plane, plane will follow one of the three distinct paths, according to applied longtidual stimulus. (pitching) First phase is “statically stable.” Center of gravity of plane must be in front of the aerodynamic center of the plane, in order to be statically stable.(See Diagram 4.) When a plane is statically stable, its' physical properties form a negative feerdback mechanism, preventing formation of fatal changes in vertical path of the plane. Therefore plane can manage to fly long distances without any active elevators. In my experiment I observed my glider also exhibits these properties when its' center of gravity is at between +2.4 cm and +0.6 cm. This statement of mine depends on the horizontal displacement of the glider between these two points, which includes the peak mean range of 658.8 cm(+/- 0.152%).

Second phase is “statically neutral” phase. Plane or glider will be statically neutral when horizontal positions of the aerodynamic center and center of gravity corresponds. Since this phase is based on an equality, its' range is limited. During this phase, physical properties of plane or glider neither aids nor reverses the stimulus made on vertical flight path of the plane. Without any feedback, plane will continue to change its' direction according to the stimulus, until any other stimuli is applied. Neutral point of longtidual static stability of the paper glider used during the experiment must correspond placement of center of gravity between + 0.4 and + 0.6 cm's from datum connecting wightips of the plane, but no exact location can be determined. I deduced this because plane was neither stalled, nor flew so long and I observed that it continued to its' fall coherent to the neutral stability conditions.

Third phase is “statically unstable” phase. Plane or glider will be statically unstable when its' center of gravity falls behind of its' aerodynamic center. Physical properties of a statically unstable plane or glider has a positive feedback mechanism, which makes plane open to the fatal changes in flight path. Data group below 0.4 cm on x axis indicates statically unstable glider, which can manage to fly only a short distance, then land. Positive angle of attack of the glider in the experiment was similar to a pitch up stimuli. I observed that unstable glider responded by increasing its' angle of attack, approximating 90 degrees with respect to the ground. Then its' velocity decreases enough for a stall, causing plane to crash onto ground in the end.

As a result, diffrent phases of stability causes glider to follow distinct horizontal flight paths, regardless of its other properties. Datas shown on graph 1 fits properly to this distinction. Experimental practice is coherent with theory, formulating a conclusive result.

Secondly, best fit curve bends down after peak around 2.0 cm on x axis. This behavior of glider indicates an optimum range for placement of center of gravity relative to line connecting the wingtips. Cause of this effect is net torque applied to the glider by gravitational force. When net torque is applied around aerodynamic center, plane will pitch up or down, according to the direction of torque. In this occassion, net torque applied around aerodynamic center causes plane to pitch down. With further movement of center of gravity towards the nose, net torque around aerodynamic center increases, causing more effective pitching down, shortening its' range.

Thirdly, even if the glider was stated to be statically unstable for the datas up to 0.4 cm on x axis, it managed to flew at least 151.6 +/- 0.05 cm.Cause of this is force applied to the plane by the rubber band used for throwing the plane. Tensile energy stored in the rubber band was effectively trasfered to the glider as kinetic energy. This kinetic energy caused glider to flew that distance. During the experiment, I observed that glider always tends to increase its' angle of attack after the launch. Therefore it reduced its' horizontal velocity significantly. So distance flown by the glider is affected negatively by its' physical properties in this phase.

At next, equation of the best fit curve was determined for data set on x axis ranging from -1.0 to + 2.6 cm. Beyond these points, behavior of the glider was unknown, making the extentions of curve beyond them unreliable. Another reason for this; extensions will continue to extend to the infinity in both x and y axis mathematically, therefore, results indicated will soon become impossible to achieve, due to the physical impossibilities. Because of lack of experimental knowledge beyond these limits, the results are only applicable within the experimented range of placement of center of gravity relative to the datum connecting the wingtips of the plane.

Calculation of an error range from best and worst fit lines is not possible as made with a linear relationship since there was no gradient can be calculated. Instead, standard deviation values with error bars on the graph 1 for data groups were used as a measure to test trusthworthiness of the results. Standard deviation, variance values were indicated in Table 2 in previous sections and error bars were added on Graph 1. Error values and their implicaitons will be inspected broadly in next secction.

Limitations to Conlusion

In the first place, standard deviation values for every data group indicates relatively high values. Even the lovest value on Table 2 indicates a standard deviation of 17.1 cm, for the last data group. Other values were increase up to 161.7 cm. Based on the definiton of the standard deviation it can be stated that entries forming data groups were relatively spreaded widely within data group. Due to large gaps between individual entries of data groups, precision of groups decrease, reducing possibility to formulate a trustworthy statement. Even if 50 trials were performed, randomness in results contiune to be an important issue, related to precision. Lack of precise data eventually makes it impossible to formulate highly certain conclusion. Because of that, important questions will arise about trustworthiness of the results.

In the end, the result can not be taken as conclusive as advanced reports prepared by scientific authorities, due to apparent randomness in datas. Presence of the randomness in datas were balanced with number of trials performed during the experiment, since it will help to formulate more reliable data set, increasing the trustworhiness of the result. In addition, error ranges in Graph 1 was not significant as standard deviations of data groups, positively affecting precision of the result. Based on these reasons, the conclusion will be classified as neither uttermost precise nor extermely inconclusive; but as satisfactory, somewhere closer to an uttermost precise result. It was not without its' indisregardable limitations, but formulate adequetly reliable conclusion.

Further Questions Arised from the Result

Aircraft used in the experiment has a definite properties. Therefore result covers aircrafts having similar properties. Other types of aircraft, may exhibit different behaviors under same variables. This experiment can not provide sufficent data for supersonic flight, due to the changing fluid dynamics and doppler effect created at speeds around 1.0 mach.

Also different wing types and instrument arrangements will result in different flight dynamics, which supports the fact that the result is exculsive for a certain type of aircraft. But how the construction of the aircraft affects its' response? Canard type, straight wing, swept wing and delta wing aircraft has their own distinctive constructions, therefore different flight characteristics.

Moreover, in the real life, aircrafts were made from materials such as alloys or petroleum products. Their rigidity is incompareably more than glossy paper. Paper aircraft will exhibit a deflection on its' wing profile due to the fast movement of air above and below the wing. More rigid materials used in real aeroplanes and gliders were much more rigid and exhibit minimal deflection.

Tested aircraft was a simple glider, lacking any dynamic control surfaces and engine. Therefore its' dynamics become much simpler. But it is not at all related to a real aeroplanes with dynamic controls.

3814 words.

Appendix

Table 1 (Constant Variables)

Temperature (+/-0.05 °C)	Air Pressure (+/- 0.05 mb)	Humidity (+/- 0.05%)	Wind Speed (+/-0.05 ms^{-1})	Weight of paper aeroplane and paperclips (+/- 0.01 g)	Angle of Attack at Launch (+/- 0.1 degrees)
27.40	1007.40	35.00	0.00	12.12	0.0

Table 2 (Raw Data Table)

Horizontal Distance Between Center of Gravity and Line Connecting the Wingtips of the Plane (+/-0.05 cm)*	Flight Distance (+/-0.05 cm)
+2.6	531.7
	696.8
	666.2
	504.7
	530.4
+2.4	557.5
	551.0
	680.0
	657.6
	274.0
+2.2	604.4
	515.0
	484.0
	573.1
	589.0
+2.0	647.3
	592.3
	608.5
	647.5
	798.5

+1.5	649.5
	568.0
	504.0
	607.5
	644.6
+0.8	374.9
	641.6
	511.3
	473.0
	532.0
+0.6	501.0
	565.7
	529.0
	478.3
	513.5
+0.4	274.4
	365.3
	272.6
	255.5
	286.8
-0.5	255.4
	168.0
	241.8
	145.6
	246.3
-1.0	151.6
	173.5
	197.0
	160.4
	175.0

* Distances towards the nose of the plane was denoted with “+” whereas distances towards the tail of the plane was denoted with “-”.

Table 3(Processed Data Table)

Horizontal distance between center of gravity and line connecting the wingtips of the plane (+/-0.05 cm)	Horizontal Displacement (+/-0.05 cm)	Average Horizontal Displacement (cm)	Variance	Standard Deviation
+2.6	531.7	586.0 (+/- 0.174 %)	7839.6	88.5
	696.8			
	666.2			
	504.7			
	530.4			
+2.4	557.5	634.0 (+/- 0.160 %)	20906.4	161.7
	551.0			
	680.0			
	657.6			
	274.0			
+2.2	604.4	553.1 (+/- 0.155 %)	2636.7	51.3
	515.0			
	484.0			
	573.1			
	589.0			
+2.0	647.3	658.8 (+/- 0.152 %)	6682.1	81.7
	592.3			
	608.5			
	647.5			
	798.5			
+1.5	649.5	594.7 (+/- 0.134 %)	3649.1	60.4
	568.0			
	504.0			
	607.5			
	644.6			
+0.8	374.9	506.6 (+/- 0.142 %)	9341.5	96.7
	641.6			
	511.3			
	473.0			
	532.0			

+0.6	501.0	517.5 (+/- 0.194 %)	1070.1	32.7
	565.7			
	529.0			
	478.3			
	513.5			
+0.4	274.4	290.9 (+/- 0.173 %)	1853.1	43.0
	365.3			
	272.6			
	255.5			
	286.8			
-0.5	255.4	211.4 (+/- 0.250 %)	2572.8	50.7
	168.0			
	241.8			
	145.6			
	246.3			
-1.0	151.6	171.5 (+/- 0.294 %)	296.4	17.2
	173.5			
	197.0			
	160.4			
	175.0			

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Programs Used

1. Logger Pro 3.8 by Vernier Software. Used for plotting graph 1.