International Baccalaureate

Extended essay cover

SAMPLE A

Diploma Programme subject in which this extended essay is registered: Physics

(For an extended essay in the area of languages, state the language and whether it is group 1 or group 2.)

Title of the extended essay: Investigation of the effects the change in vertical centre has on the stability of a canoe

Candidate's declaration

If this declaration is not signed by the candidate the extended essay will not be assessed.

The extended essay I am submitting is my own work (apart from guidance allowed by the International Baccalaureate).

I have acknowledged each use of the words, graphics or ideas of another person, whether written, oral or visual.

I am aware that the word limit for all extended essays is 4000 words and that examiners are not required to read beyond this limit.

This is the final version of my extended essay.

Candidate's signature: ______________________ Date: 13/2/09

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International Baccalaureate, Peterson House,
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Supervisor's report

The supervisor must complete the report below and then give the final version of the extended essay, with this cover attached, to the Diploma Programme coordinator. The supervisor must sign this report; otherwise the extended essay will not be assessed and may be returned to the school.

Name of supervisor (CAPITAL letters) ______________________________

Comments

Please comment, as appropriate, on the candidate's performance, the context in which the candidate undertook the research for the extended essay, any difficulties encountered and how these were overcome (see page 13 of the extended essay guide). The concluding interview (viva voce) may provide useful information. These comments can help the examiner award a level for criterion K (holistic judgment). Do not comment on any adverse personal circumstances that may have affected the candidate. If the amount of time spent with the candidate was zero, you must explain this, in particular how it was then possible to authenticate the essay as the candidate's own work. You may attach an additional sheet if there is insufficient space here.

The student asked me for an idea. I suggested to investigate the stability of a small boat, 14 feet. He wanted more to investigate the stability of a conoe, since there has been remarkably many accidents with these. What could the reason be?
The tests, for obvious reasons, could not be performed at our school, but he frequently told me about problems he was working on. Though his writing has a few „writing mistakes", the interviju showed that he had good controll of the theory, and we could discuss details from the investigation easily.

I have read the final version of the extended essay that will be submitted to the examiner.

To the best of my knowledge, the extended essay is the authentic work of the candidate.

I spent 1,5 hours with the candidate discussing the progress of the extended essay.

Supervisor's signature: ______________________ Date: 13.02.2009

Extended Essay in Physics

Investigation of the effects the change in vertical centre of gravity has on the stability of a canoe

(what about centre of buoyancy?

Word Count: 3510

The determination of position of C of G of canoe is elegantly done. The recalculation based on various additional equipment is glossed over & the presence of a canoeist is ignored - not sure why. The relationship between inclination and toppling torque is quite well treated, but once he starts introducing centre of buoyancy and metacentre he fails to show further understanding. Analysis stops & the essay degenerates into qualitative verbosity. Uncertainties are not considered. The main result is somewhat obvious from the start - but at least he did substantial experimental work, applied some physics to the situation and arrived at a reasonably sensible conclusion - albeit with some weaknesses

Abstract

RQ

This essay studies the effects the change in vertical centre of gravity has on the stability of a canoe. The research is conducted with the performing of an "inclining test". Moving the Vertical Centre of Gravity (VCG) by adjusting the height of a 10 kg deadweight by moving it upwards an locking it in different position on the mid pole. And for each new posistion add increasing weight on the side to create an overturning moment, causing the canoe to gain an angle of inclination. The results were recorded by suspending a plummet from the top of the mid pole, so that it hung freely and would not be subject to any other forces than gravity. Thus whilst gaining an inclination angle, the plummet will react accordingly. Making the angle of inclination calculable by trigonometri. In calculating the VCG of the canoe, the canoe was hung on the side creating measurable force pairs, which then made the VCG calculable. Also, all equipment mounted in the canoe was weighd, and its momentum calculated relative to the height it was placed at. Giving the overall VCG when all equipment was mounted in the canoe.

how investigation was undertaken

S

The research showed an exponential relation between VCG and inclination angle, as the VCG also affected other factors involving the stability of the canoe.
Overall this investigation shows that the VCG is a substantial factor in the stability of a canoe, although different hull constructions might be affected differently, it will still remain one of the most important factors.

concl.

C

Word Count: 252

2/2 all elements clear

Table of Contents

1. Introduction

1.1 Background

Several people die every year due to canoe accidents. The reason for this may be due to little experience with canoes. Often people have limited knowledge of how the canoe acts in water, and how sensitive its stability is to changes of the vertical centre of gravity, e.g. when lifting a heavy object from the bottom of the canoe, thus moving its Vertical Centre of Gravity (VCG) upwards. Therefore it is interesting to see how much this vertical change influences the stability of the canoe.

1.2 Objective

The objective of this study is to find the connection between the change in VCG and the angle of inclination that the canoe develops when weight is added on the side of the canoe, i.e. finding the answer to the question:

"How does the change in vertical center of gravity affect a canoe's stability?"

intro: no mention of righting moment / torque but stability of canoe under ... implicit ... b.o.d.

RQ 2/2

=> canoe rolling re main axis

2. Equipment description and setup

2.1 General description

p7 — figure 1 ?

The equipment used to perform the experiment is shown in picture 1, and may be described as follows:

the pole is not identified on picture 1

1. A vertical pole is fixed in the centerline, at the amidships section of the canoe. This was done by fixing a transverse support, with a drilled hole for the pole, to the gunwale amidships. Likewise an anchoring support for the pole was fixed to the bottom of the canoe.

2. A 10kg deadweight was used to change the VCG by sliding and locking it at different levels of the pole.

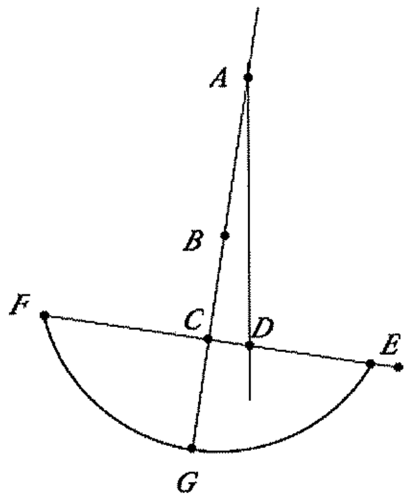
3. A transverse stay was used to prevent bending of the centre pole.

4. To create a roll moment, additional weights were added on to a side pole fixed to the starboard side of the canoe.

5. To measure inclination angle of the canoe, it was used a plummet suspended from the top of the pole and a measuring stick positioned horizontally at the same level as the transverse support.

(* b.o.d. : benefit of the doubt)

2.2 Schematic setup



good

Figure 1

The setup of the experiment is shown schematically in Figure 1 above. B represents the weight being moved upwards to change the VCG.

At E the additional weight was added to create a roll moment, thus giving the canoe an angle of inclination. This inclination angle is calculated by the use of trigonometry. A plummet was suspended from A so that it hung freely and would not be subject to any other forces than gravity. Thus as the canoe gained an angle of inclination when additional weight was added at E, the plummet gave a point D, thus the side CD was measurable. Hence all sides and angles of the triangle ACD can be calculated with the use of trigonometry.

E, F masses change CoG too

? At point F balance weight was added so that when no weight was added at E, the plummet would hang parallel to the mid pole. Hence the inclination angle would be 0, and the transverse CoG is in the centerline. This was needed to balance the canoe as the equipment mounted in the canoe displaced the transverse CoG towards the right. Thus making the canoe tilt slightly towards the right.

a bit confusing here

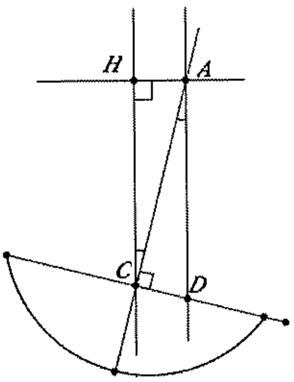


Figure 2

(nothing new here)

By constructing a horizontal perpendicular through point A, and a vertical perpendicular through point C. They will intersect at H, thus creating a new triangle, HCA. This triangle will then have the same angles as ACD, subsequently the angles CAD and HCA are equal. Looking at Figure 2 above we see that the angle HCA is the inclination angel of the canoe. Hence calculating the angle ACD will give the inclination angle, as the angles are equal. is this something new?

– Can the essence of the experiment/principles be explained in a few lines so we know where we are going?

3. Procedure

3.1 Preparation

3.1.1 General

Before performing the experiment, it was important to find the position of the CoG, both in longitudinal, transverse and the vertical direction. This was done as described in sections 3.1.2 through 3.1.4

3.1.2 Longitudinal CoG

As this investigation aim only to find how the vertical CoG affect the transverse stability of the canoe, the longitudinal CoG needs to remain the same throughout the experiment. Therefore the pole carrying the movable weight needs to be placed at the longitudinal CoG so that it will not affect the results. good

Finding the longitudinal CoG is easily done, by rolling the canoe over a cylindrical pole on a smooth surface until the canoe stays on top of it, not tilting to either side. This is illustrated by picture 1 and is *shown schematically in Figure 3 on the following page.*

any value to suggest? (with ± ?)

Picture 1

not very useful on page ..

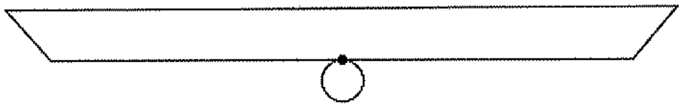


Figure 3

3.1.3 Transverse Centre of Gravity

(not the best presentation/organization)

During the experiment the transverse centre of gravity needs to be in the centerline. As further described in section 3.2, this is obtained by adding a balancing weight to make the canoe float with no initial list.

3.1.4 Initial vertical CoG

diagram ?

moment is not momentum

Furthermore, to be able to estimate how heavy weight that should be used to move displace the vertical CoG, and the height of the pole being used to hold the weight at fixed positions should be. It was crucial to know the vertical CoG of the empty canoe. So that by calculating the momentum (mass of weight multiplied with height), it was possible to examine the effect it would have on the vertical CoG of the canoe.

To establish the vertical centre of gravity of the empty canoe, it was necessary to carry out the two-weighing/measuring operations described below.

diagram

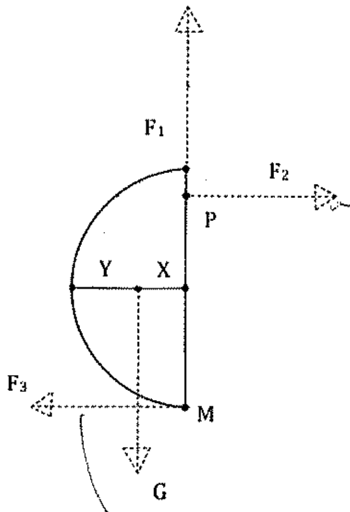
Firstly, the weight of the canoe was found by hanging it from one rope at each end of the canoe, measuring the force at each of the ropes. The measurements were done using a scale with a working range 0-25 kg and the results were as follows:

curious algebra..

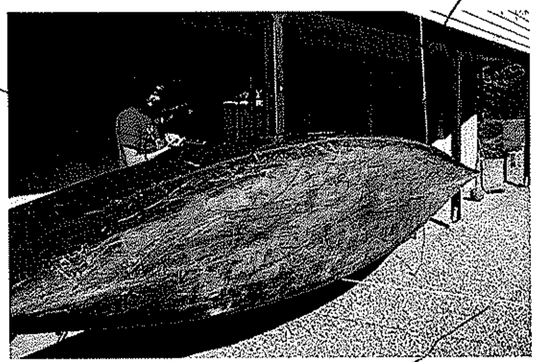
$$W = \frac{19{,}7 + 19{,}1}{2} = 19{,}4 \bullet 2 = 38{,}8 \text{ kg total weight}$$

ie not touching the ground (good)

Then the canoe was hung from the two ropes again and a turning moment was applied to the canoe by the pull of two ropes positioned at the longitudinal centre of gravity. The ropes were pulled until the canoe was hanging on its side as shown in picture 2 ensuring that the ropes carrying the weight of the canoe were hanging vertical and in a position 90° to upright position. In this way the two ropes created a force couple and the upper force was again measured by using the scale. Schematically the setup is shown in figure 4 below.



not vertical



Picture 2

Figure 4

Y equals the VCG of the canoe, thus meaning that if X is found, X can be subtracted from the height of the canoe, which is YX to give the vertical CoG Y.
The force couples are two equal, but oppositely directed forces acting simultaneously on opposite sides of an axis of rotation. So in this case we have that $F_1 = G$ and $F_2 = F_3$, thus as angle between F_1 and the canoe is 90° the moment~~um~~ of the rotational forces acting on point M are equal.

(Mg ?) again

The magnitude of the force couple is the sum of the products of each force and its moment arm.
This gives that $PM \bullet F_2 = X \bullet 2$, solving for X we get $\frac{PM \bullet F_2}{G} = X$, as all the other forces and lengths are measurable we get $\frac{76,5 \bullet 14,1}{38,8} \approx 27,8cm$. Hence as YX equals 47cm Y = 47-27.8 =19.2cm.

±?

some uncertainty that near vertical support ropes are also adding to the turning moment provided by F_2 & F_3

3.1.5 Vertical centre of gravity including equipment

which "equipment"?

As all the equipment mounted in the canoe will also affect the vertical CoG, so the sum of the ~~momentum~~ of all the parts divided by their weight will give the resulting CoG. Shown in Table 1.

momentum - again (language)

mass kg

Units kg cm

Item	Weight	COG(cm)	Moment
Canoe	38,80	19,20	744,96
Bottom support, longitudinal	1,13	0,95	1,08
Bottom support, transverse	0,33	3,05	1,00
Upper transverse support	2,71	37,00	100,27
Sidepole	0,13	63,00	8,00
Side pole support	0,22	40,45	8,70
Mid pole	0,60	109,50	65,70
Ballance weight	2,00	39,00	78,00
Sum	**45,92**	**312,15**	**1007,71**
Resulting COG		**21,95**	

mass vs weight, units missing => name language se weak wrong

no passenger?

→ sig. fig.

→ any ±

± ?

Table 1

~~bottom rim of canoe~~ above base of canoe

Its now possible to examine what effect a weight of e.g. 10kg will have on the VCG of the canoe.

A weight of 10kg placed 80cm above the bottom of the canoe will have a momentum of 800, if this was added to the table above the resulting CoG would be approximately 32cm, which means that the weight has moved the VCG 11.5cm upwards. Hence a weight of 10kg was believed to be sufficient when conducting the experiment. Canoe passenger not considered.

units

3.1.6 Mounting the equipment

The equipment was mounted in the canoe with respect to the above mentioned controlled parameters (see section 2.2), hence the pole was placed in the intersection between the longitudinal and transverse CoG. Each part was weighed and its momentum was calculated with respect to its position in the canoe relative to the keel, so that the resulting VCG was under control (see Table 1). A wire was connected from the top of the pole and to the side of the canoe, so that when the canoe gained an inclination angle, the weight would not bend the pole and affect the inclination angle, thus the weight would stay at its designated position at all times.

impact of wire on net moment? (only 1 wire?)

see picture 4

3.2 Conducting the experiment

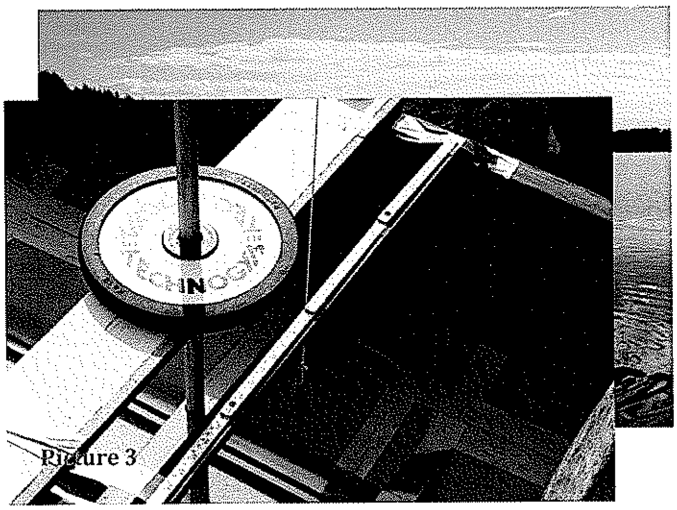
hence buoyancy forces now appear and forces are not considered in theory.

After placing the canoe on water, the first thing to be done was to add balance weight so that the plummet would hang parallel to the mid pole, and reassuring that the canoe was perfectly still while doing this.

Then, with the weight placed at its initial position, one by one weights of 1kg each was placed on the side pole. The new position of the plummet was measured and noted for each of the added weights.

After a total of 6 recordings, the weights on the side pole were removed. And the weight on the mid pole was moved to its second position. Again it was reassured that the plummet was parallel to the mid pole before adding weight on the side pole. As the first time one by one, weights of 1kg were added, and the position of the plummet was noted.

Repeating this a total of four times, but at the third and fourth position of 10kg it was not possible to add all six weights on the side pole. As the canoe was no longer able to gain an equilibrium at its new inclination angle, but would capsize by the slightest touch.



Picture 3

Picture 5

Picture 4

wire + plummet can be seen

unclear

4. Data collection and processing

4.1 Raw data

The raw data collected during the procedure is noted in the Table 2 below.

for what position of the 10kg mass is this ??

	Plummet displacement (cm)			
Additional weight (kg)	Position 1	Position 2	Position 3	Position 4
0	0	0	0	0
1	2,5	4	5	7
2	6,5	8,5	11	16,5
3	10,5	14	19	31
4	14	19,5	31,5	X
5	19	27,5	X	X
6	25	36,5	X	X

(±?) (sig. dig. ?)

±? (25.0 cm ?

✓ Table 2

Seen from the Table 2 above, no data was collected for added weight >4kg at position 3 and >3kg at position 4. This was because, as mentioned earlier, the canoe did not have enough righting momentum to keep it from rolling over.

to be explained later.. (p13)

4.2 Processed data

The inclination angle in degrees is calculated by dividing the plummet displacement by the length of suspended line attached to the plummet (measured to 179cm). Arctan of this value then gives the angle in radians, muliplying this with $\frac{180}{\pi}$ then gives the inclination angle in degrees.

Ex. For the first recorded displacement at position 1

±?

$$\angle = \tan^{-1}\left(\frac{2.5}{179}\right) \bullet \frac{180}{\pi} = 0.80^{\circ}$$

or easier set calculator to degree mode!

The rest of the processed data is given in Table 3 below.

±?

N? Kg?

	Inclination angle (Degrees)			
Weight	Position 1	Position 2	Position 3	Position 4
0	0	0	0	0
1	0,80	1,28	1,60	2,24
2	2,08	2,72	3,52	5,27
3	3,36	4,47	6,06	9,83
4	4,47	6,22	9,98	
5	6,06	8,73		
6	7,95	11,53		

✓ Table 3

No uncertainties

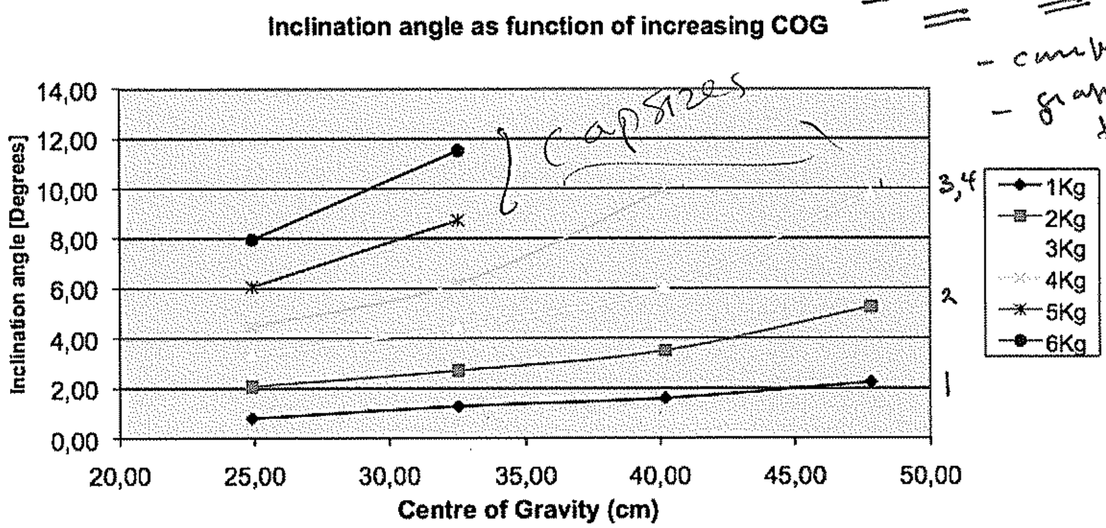
See Figure 2, page 6, and the text following it for further explanation. . . . { presentation not well organized.. }

5. Data presentation and analysis

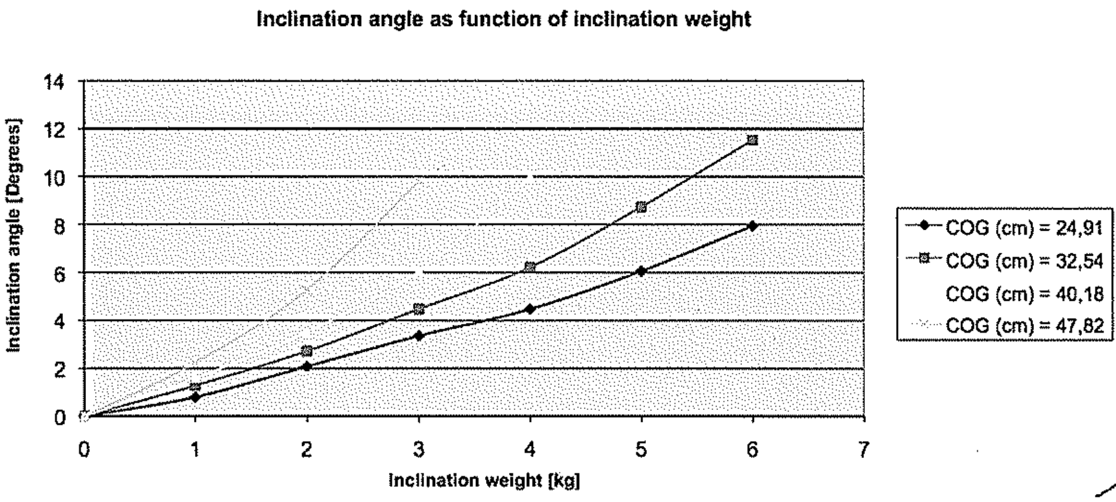
5.1 Presentation

The processed data is presented in the two following graphs:

- no error bars
- complete grid
- graph too small...



✓ Graph 1



function

Graph 2

5.2 Analysis

not at all! (not proper language)

wrong ? ...

Obvious from Graph 1 above is that the inclination angle grows exponentially with the COG, but the growth differs with different weight added on the side.
Graph 2 on the other hand shows how the canoe acts for more weight put on the side for each specific COG. Interesting to note from Graph 2 is the largest inclination angle recorded, which is nearly 12°. As in the two next positions it was not possible to add as much weight on the side and as the canoe would not have enough righting momentum to keep it stable. Looking closer the increase in inclination angle between each added weight, it is noticeable that the increase is so large that the next point in both cases would be expected to be exceed 12° by >2°. And observed during the experiment was that the canoe's stability at the largest recorded inclination angle was almost non existing and the smallest weight added by touching it caused it to loose all its stability. By this it is possible to assume that the canoe's maximum inclination angle. ? B ?

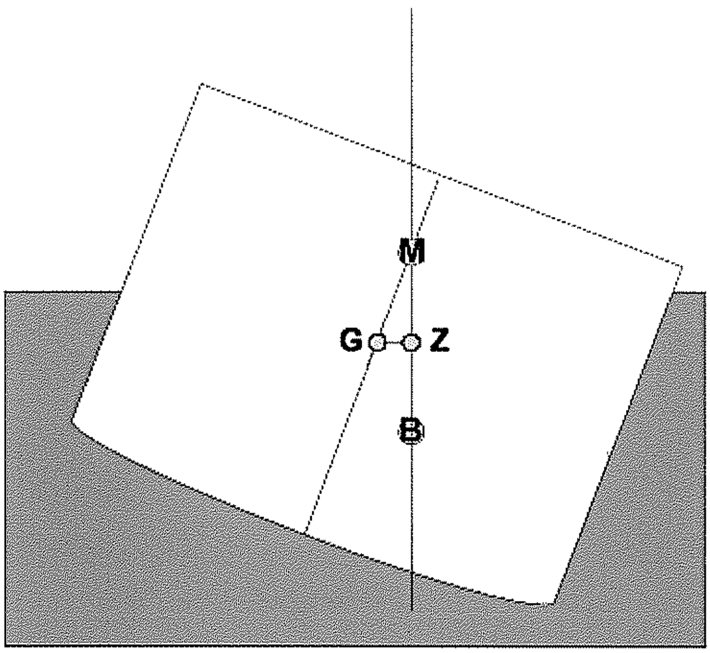
not very clear use the graph to illustrate the argument or use the graph

For further analysis of the results it is necessary to have some idea of these terms; center of buoyancy, metacenter, metacentric height (GM), GZ (righting arm). All displayed in Figure 5 below.

any references?

- The center of buoyancy is the COG of the volume of water, which the hull displaces.
- Metacenter M is the point at which a vertical line through the tilted center of buoyancy crosses the line through the original, non-tilted center of buoyancy. Considered to be fixed for small angles (up to 10°).
- Metacentric height (GM) is the distance between the metacenter and the COG.
- GZ, otherwise known as the righting arm, is the horizontal distance between the center of buoyancy and the center of gravity. And is a theoretical lever through which the force of buoyancy acts.

(not a canoe! ie very flat bottom)



no analysis here – poor!

Figure 5

Source: http://en.wikipedia.org/wiki/File:Metacentre.png

In this experiment G (referring to Figure 5) is being moved upwards by using 10 kg deadweight. Thus the metacentric height decreases for each position the deadweight is moved upwards. Subsequently the righting arm (GZ) will also decrease with it, leading to an overall smaller righting momentum, as the force of buoyancy acting on GZ does not change.

If G is moved above M, the stability is said to be negative, as there is no lever for the force of buoyancy to act on. If this were to happen, either capsize or heel until the metacenter is increased and has exceeded G. But an increase of metacenter is dependent on the structure of the hull.

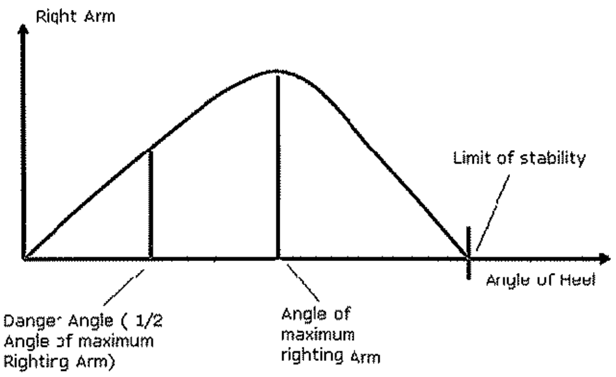
The observation of the canoe not having enough momentum to keep stable beyond $\leq 12^{\circ}$. Is a result of the metacenter (M) moving downwards (towards G), this is due to the flat bottomed construction of the hull. When the canoe gains an angle of inclination beyond 12°, the waterline reaches the edges leading to the bottom of the canoe. This changes the waterplane area drastically, which affects the metacenter since the metacenter can be calculated by the formula below.

$$BM = \frac{I}{V}$$

Where B is the center of buoyancy, I is the moment of inertia of the waterplane's area and V is the volume of water the hull displaces. B and V being equal as I decreases, M will subsequently decrease as well. Thus the metacenter moves downwards towards G, and as previously explained a smaller metacentric height gives a smaller righting momentum.

Also interesting in Graph 1 is the fact that for small weights added e.g. 1-2 kg, the effects of a higher VCG seems to have little effect on the inclination angle. It is of course an increasing angle as the VCG increases but only by few degrees. E.g. for 1kg added, an increase of VCG from 25 cm to 48 cm only results in the inclination angle increases 1,44°. As opposed to 3kg where the same increase of VCG gives an increase of 6,5° inclination angle, which is more than 4 times the same increase for 1kg. Although the metacenter stays fixed, the center of buoyancy will move in an arc around the metacenter, and it will tend to the side the canoe heels because the volume of water displaced by the hull will shift to that side, thus changing the displaced waters COG i.e. the center of buoyancy. Henceforth as G remains fixed as the canoe heels, the Z moves away from it, increasing the righting arm (GZ) and the canoe's ability to stay even keeled. ✓

"GZ curve"



source?

Graph 3

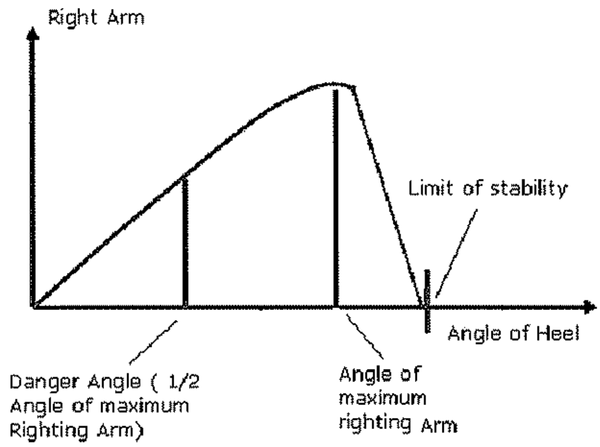
for which "vessel"?

Graph 3 is an schematically drawn GZ-curve, which is the most commonly used way of show the stability of a vessel. It will differ from vessel to vessel, but the above graph shows the most usual way it appears. And it clearly confirms how the stability of the canoe acts. For small angles it has an increasing righting arm, but upon reaching the maximum angle it decreases rapidly, as the center of buoyancy shifts. In this experiment, we also had an added effect of the metacenter moving downwards, decreasing the metacentric height, due to the construction of the hull. Wheras in a normal vessel, the hull is designed so that the metacenter increases when it gains larger angles. So when the buoyancy moves back towards the center after reaching its maximum, the hull is constructed so that the metacenter increases. This slows down the decrease of GZ, allowing the maximum angle of heel to be beyond maximum righting arm. Therefore, normal vessels have GZ-curves similar to the one above, where the maximum angle of heel is reached long after reaching the maximum righting arm.

of canoe .. elaborate

(canoe or not canoe)

the order of the discussion and the order of the GZ graphs/curves #3 & #4 not helping the "follow-up" of the argument



Graph 4

Any theory behind these interesting graphs? .. lost opportunity re an essential aspect of the canoe stability

However, for the canoe the metacenter stays fixed until it reaches what is believed to be its maximum righting arm. And then both the metacenter and the center of bouyance shifts towards the center of gravity. Causing the canoe to loose all its stability and thus it will capsize. Hence the GZ-curve would be similar to Graph 4 above.

Last section is very qualitative & difficult to follow.

6. Conclusion and evaluation

6.1. Conclusion

It was noticeable that the relation between VCG and inclination angle is exponentially increasing with the VCG. This was because the stability of a canoe is dependent on numerous variables, most importantly metacenter, center of buoyancy and VCG.

No

not precise & not proven

In this investigation the aim was to assess how the use of VCG as an independent variable would change the stability, and although not measurable, the two other before mentioned variables are dependent on the inclination angle. And act differently for different angles:

- For small angles ($\theta < 12^o$), the metacenter is believed to stay fixed.
- The center of buoyancy will move in an arc around the metacenter, depending on COG of the water the hull diplaces.
  - Reaching a maximum angle, it will tend towards the center again.
- For larger angles ($\theta > 12^o$) the metacenter is believed to change, depending on the hull structure.
  - In this case, towards the VCG.

The effect of an increasing VCG is that the metacentric height decreases, giving a smaller righting arm. Subsequently the canoe gains larger inclination angles more easily, which then causes the other variables to act in a way that decreases the stability. Thus the effect of moving the VCG upwards becomes an exponential one, with regard to inclination angle.

6.2 Evaluation

Although a probable conclusion, this investigation suffers from many sources of error:

- It was conducted in an open environment
  - Low accuracy in measurements
    - Affected by waves and wind
- Measuring the angle of inclination was not to accurate, as it was hard to obtain an equilibrium.
- Center of buoyancy and metacenter not measurable
  - These calculations are far too advanced.
    - E.g. metacenter is calculated by integration of crossections of the canoe.

introduce ± values, not done here

no attempt possible even by approximation?... an interesting question to consider;

Some imporvements could then be:

- Conducting the experiment in an enclosed environment.
- Using a canoe with a known metacenter.
- Better measuring instruments.

However, the results seemed probable, and were all explainable by known factors affecting the stability of a canoe.

---

investigation: good data, very limited bibliography but still some relevant info gathered;

knowl.: basic concepts understood (torque, moment arm, righting arm..) in first part; general principle of the righting arm understood but no quantitative / theoretical approach attempted.

reasoning: good

analysis / evaluation: uncertainties / signif. digits not taken into account; a curve qualified as exponential is evidently not; 2nd part (buoyancy, righting arm) superficially analyzed, qualitative + descriptive only;

language: why use momentum for moment? why not use the word "torque" ..? some units missing, weight + mass confused; picture / diagram not fully used to transmit knowledge; misuse of "exponential"; 3, almost 2..;

conclusion: partly consistent, relevant;

presentation: organization not ideal, at times difficult to know where the essay is going (righting arm concept comes late); graphs too small, no complete grid, except for one, references in biblio not cited in essay; no access dates;

holistic: original / interesting idea, good experimental execution, creativity; for top mark the theoretical challenge (buoyancy etal) should have been faced up-front (possibly using iteration, or an "approximative" approach;

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Bibliography

http://en.wikipedia.org/wiki/Inclining_test

http://en.wikipedia.org/wiki/Bouyancy

http://en.wikipedia.org/wiki/Naval_architecture

http://en.wikipedia.org/wiki/Metacenter . png

http://school.eb.co.uk/all/eb/article-9052261?query=metacenter&ct=null

all wikipedia

→ date of access ?

→ very limited biblio.

* only reference cited in core of essay

(standard not followed)

Assessment form (for examiner use only)

Candidate session number	0	0							

		Achievement level		
		First examiner	maximum	Second examiner
Assessment criteria	**A** research question	2	2	2
	B introduction	2	2	2
	C investigation	3	4	3
	D knowledge and understanding	3	4	3
	E reasoned argument	3	4	3
	F analysis and evaluation (no uncertainties)	2	4	2
	G use of subject language	3	4	3
	H conclusion	1	2	1
	I formal presentation	3	4	2
	J abstract	2	2	2
	K holistic judgment	3	4	3
	Total out of 36	27		26

Name of first examiner: ______________________ Examiner number: __________
(CAPITAL letters)

Name of second examiner: ______________________ Examiner number: __________
(CAPITAL letters)