CHAPTER 1
INTRODUCTION

The world's first oil tankers appeared in the late 19th century and carried kerosene for lighting, but the invention of the motor car fuelled demand for oil [4]. A tank ship or tankship, often referred to as a tanker, is a ship designed to transport liquids in bulk. Major types of tankship include oil tanker, the chemical tanker, and the liquefied natural gas carrier [6].

Tankers can range in size of capacity from several hundred tons, which includes vessels for servicing small harbours and coastal settlements, to several hundred thousand tons, for long-range haulage. A wide range of products are carried by tankers, including hydrocarbon products such as oil, liquefied petroleum gas (LPG), and liquefied natural gas (LNG), chemicals, such as ammonia, chlorine, and styrene monomer, and etc [6].

There are two basic types of oil tanker which are crude tanker and product tanker. Crude tanker can move large quantities of unrefined crude oil from its point of extraction to refineries. While product tankers, generally much smaller, are designed to move petrochemicals products such as kerosene, diesel, and etc from refineries to consuming market [6].

1.1 Background Study

Tankers are a relatively new concept, dating from the later years of the 19th century. Before this, technology had simply not supported the idea of carrying bulk liquids. The market was also not geared towards transporting or selling cargo in bulk. Therefore most ships carried a wide range of different products in different holds and traded outside fixed routes. Liquids were usually loaded in casks, hence the term "tonnage", which refers to the volume of the holds in terms of the amount of tons of wine (casks) that could be carried [4].

In 2002 an oceangoing ferry named the La Joola capsized off the West Coast of Africa between 1,034 to 1,600 crew and passengers perished in this unprecedented peace-time maritime disaster. Another recent example is the September 1997 capsizing of the Pride of Gonave in Haiti. Roughly 200 souls perished in this unfortunate debacle. In fact, stability related ferry disasters are rather common, claiming some 400 lives in Lake Victoria in May 1996; 338 lives off Sumatra in January 1996; and 852 lives in September 1994 when the ferry Estonia sank in a Baltic storm [11].

1.2 Problem Statement

Carrying bulk liquids in earlier ships posed several problems which one of the problem is free surface effect. This effect is similar to that caused by adding weight on deck, i.e. rise of the vessel's centre of gravity (**G**) which causes a decrease in the vessel's metacentric height (**GM**) and thereby its stability. It is describes about the effect a large surface area of liquid in a ship will have on the stability of that ship. See Naval Architecture, liquids in casks posed no problem, but one tank across the beam of a ship could pose a stability problem [6].

1.2.1 Problem Identification

Oil spills have devastating effects on the environment. Crude oil contains polycyclic aromatic hydrocarbons (PAHs) which are very difficult to clean up, and last for years in the sediment and marine environment. Marine species including aqueous live constantly exposed to PAHs can exhibit developmental problems, susceptibility to disease, and abnormal reproductive cycles.

The matter of stability has become one of the technical key problems in the design of such type of oil tanker. Should the computerized calculation method will be adopted to check the stability on the oil tanker by using mathematically theory, modeling of the existing stability of ship that will be applied to the oil tanker. [1]

The effect of stability will be involving the most important is human, environment and the company itself. Human who's depending on sea water usage, susceptibility to disease and abnormal reproductive.

Otherwise, for the sake of just one human life, it is worth understanding how stability works. Sadly multitudes of precious lives are lost due to a lack of awareness and understanding regarding this most crucial topic [11]. To the environment, the pollution caused by the sea damage of crude oil will exhibit developmental problems. While for the industry itself especially Oil & Gas company, for sure they having big losses of crude oil.

1.2.2 Significance of the Project

By using a Catastrophe Model for the Stability of Ship which is "cusp" Catastrophe at the metacenter, it is provides a new way of looking at the static of the ship, and to analyze the existing design based on the theory.

1.3 Objective

This project is a case study based on the existing mathematical theory, "cusp" Catastrophe at the metacenter in order to analyze the stabilization of ship current design. The sample of data boat history will be analyzing such an example or model to check the stability in the purpose to be applied specially for the oil tanker.

1.4 Scope of Study

In this case study we'll consider the simple case of ship broadside to the waves so that the wave action causes the ship to roll from side to side. Figure 1.1 below shows a ship sitting in still water. There are two forces acting on the ship which try to cause it to "sit up right". These are the weight and the buoyancy which act together to reduce the angle x. if the ship is displaced to one side it tries to restore itself and oscillates until the damping of the water brings it to rest. [7]

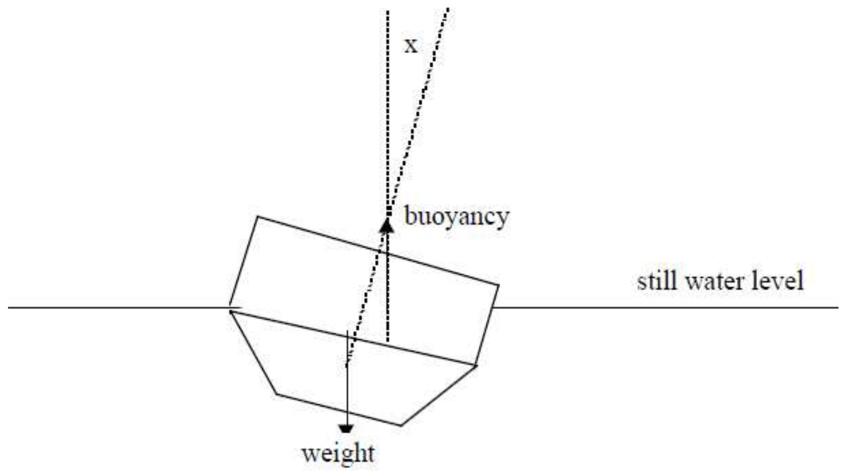


Figure 1.1: Schematic of ship in still water showing the action of buoyancy and weight to right the ship. [7]

To get better understanding about stability, the most important thing that must be consider are *weight of the object, center of gravity and moment of inertia*. This is the basic principle of the physics that interrelated to justify about the stability on the ship itself.

The weight story is described first. In nature each component of weight contributes automatically to the weight of the whole. Each weight has its own center and all the weights combined have a combined center. Determining a vessels total weight (W) and the vertical center of gravity (KG) of all weights present is basically the crux of the weights side of the story.

The design space is very large, non-linear, discontinuous, and bounded by a variety of constraints and thresholds. These problems make a structured search of design space difficult. Without a structured search, there is no rational way to measure the optimality of selected concepts relative to the millions of other concepts that have not been considered or assessed. Responsible decisions cannot be made without this information and perspective.

This is a design methodology that includes four important components necessary for a systematic approach to oil tanker concept design. These are:

- An efficient and effective search of design space for optimal or non-dominated designs
- Well-defined and quantitative measures of objective attributes, cost and risk
- An effective format to describe the design space and to present non-dominated concepts for rational selection by the customer
- A probabilistic method for predicting damage in tanker accidents and improving tanker crashworthiness

CHAPTER 2
LITERATURE REVIEW

2.1 Principle of Stability

From Naval Ships' Technical Manual (NSTM) stated that the weight of a ship in the water is "pushing" straight down, and the seawater that it displaces is "pushing" straight back up. When no other forces are acting on the ship, all these forces cancel each other out and equilibrium exists. However, when the center of gravity moves from directly above the center of buoyancy, there is an "inclining moment." When this occurs, this force is considered to be at right angles to the forces of gravity and buoyancy. An understanding of trigonometry is required to understand the effects and results of these actions [1, 5].

2.2 Case Study

2.2.1 Stability of Immersed and Floating Bodies

The book written by Clayton T. Crowe, Donald F. Elger and John A. Roberson, of Engineering Fluid Mechanics, 8th edition stated that the stability of an immersed body depend on the relatives' positions of the center of gravity of the body and the centroid of the displaced volume of fluid, which is called the center of buoyancy [1].

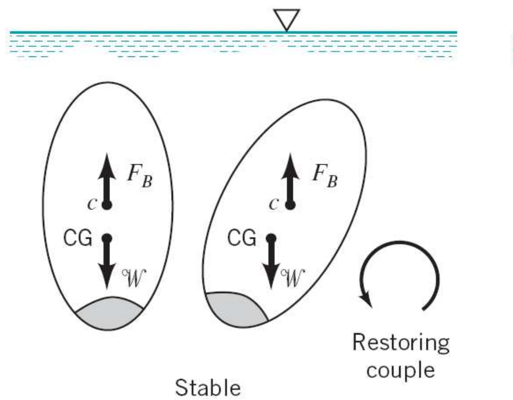


Figure 2.2: Stability of a completely immersed body – center of gravity below centroid. [1]

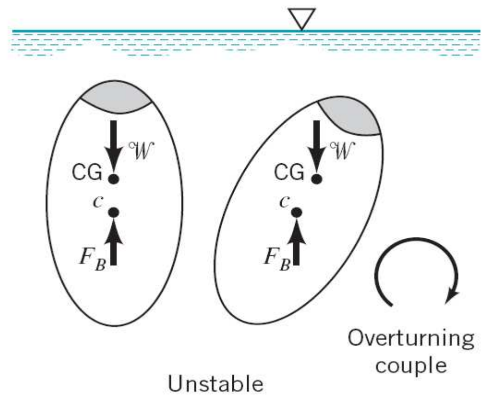
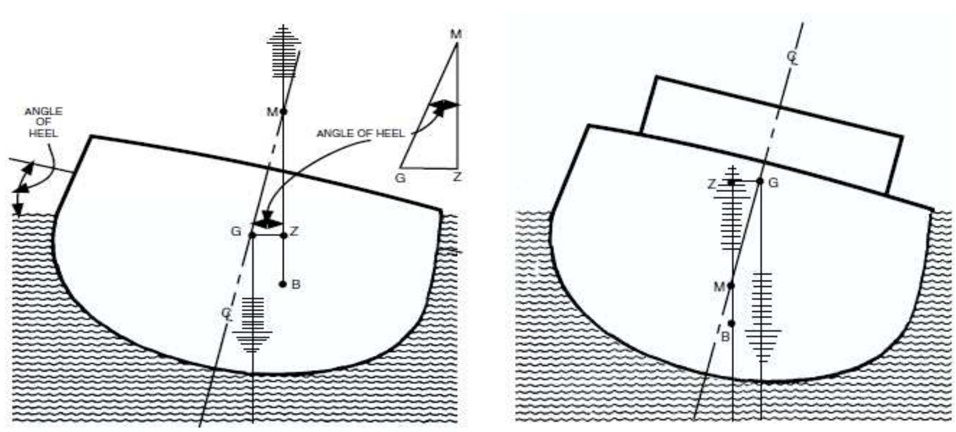


Figure 2.3: Stability of a completely immersed body – center of gravity above centroid. [1]

As in figure 2.2 shown above, if the center of buoyancy, F_B is above the center of gravity, CG any tipping of the body produces a righting couple, and consequently, the body is stable. However, in figure 2.3, it is show the center of gravity, CG is above the center of buoyancy, F_B tipping produces an increasing overturning moment, thus causing the body to turn through 180º. Finally, if the center of buoyancy and center of gravity are coincident, the body is neutrally stable in equilibrium position. [1]

2.2.2 Analysis of Stability



(a) (b)

Figure 2.4: (a) Stable condition, G is below M. [5]

(b) Unstable condition, G is above M. [5]

Referring on the Figure 2.4 above, there is stated about the laws of physics and trigonometry used to determine stability and buoyancy of a ship, and the effects of buoyancy, gravity, and weight shifts on ship stability. [5]

2. G, the ship's center of gravity, is the point at which all weights of the ship may be considered to be concentrated. [5]
3. B, the ship's center of buoyancy, is at the geometric center of the ship's underwater hull. When a ship is at rest in calm water, the forces of B and G are equal and opposite, and the points B and G lie in the same vertical line. When the ship is inclined, B and G move apart, since B moves off the ship's centerline as a result of the change in the shape of the underwater hull. [5]
4. M, the ship's metacenter, is a point established by the intersection of two successive lines of buoyant force as the ship heels through a very small angle. [5]

2.2.3 Catastrophe Theory

Originated by the French mathematician Rene Thom in the 1960s, catastrophe theory is a special branch of dynamical systems theory. It studies and classifies phenomena characterized by sudden shifts in behavior arising from small changes in circumstances.

Catastrophes are bifurcations between different equilibria, or fixed point attractors. Due to their restricted nature, catastrophes can be classified based on how many control parameters are being simultaneously varied. For example, if there are two controls, then one finds the most common type, called a "cusp" catastrophe. If, however, there are move than five controls, there is no classification.

Catastrophe theory has been applied to a number of different phenomena, such as the stability of ships at sea and their capsizing, bridge collapse, and, with some less convincing success, the fight-or-flight behavior of animals and prison riots [11].

The author of the Catastrophe theory, E. C. Zeeman (1972 – 1977) introduced that a new mathematical method for describing the evolution of forms in nature. It is particularly applicable where gradually changing forces produce sudden effect [2]. He stated that, we often call such effect catastrophe, because our intuition about the underlying continuity of the forces makes the very discontinuity of the effects so unexpected.

Quantitative Estimates

By [2] the larger the metacentric height the more stable is the ship. However, by [2] the larger the metacentric height the shorter is the period of roll, and the more uncomfortable is the ship, therefore choices of estimate metacentric height,μ is an important features of ship design.

Based on the theory, there are briefly making some very rough estimation of metacentric height, μ and period, T in order to give a quantitative feel for the problem complementary to the qualitative feel given by the subsequent catastrophe theory. Since G is too near M small alterations in the position of G may seriously increase the danger of capsizing.

The author said that, although the above assumption maybe crude the resulting orders of magnitude are not unreasonable for both naval and merchant ship. Where the ship tends to differ is in the height of G above the waterline.

Table 2.1: The example of destroyer and liner to illustrate the contrast

<table>
<tr><th></th><th></th><th>Destroyer</th><th>Liner</th></tr>
<tr><td rowspan="2">Assume</td><td>Beam, 2a</td><td>10m</td><td>30m</td></tr>
<tr><td>Height of G above water line, h1</td><td>0</td><td>2m</td></tr>
<tr><td rowspan="2">Deduce</td><td>Metacentric height, μ</td><td>0.8m</td><td>0.5m</td></tr>
<tr><td>Period of roll, T</td><td>8secs</td><td>30secs</td></tr>
</table>

As shown in the table 2.1 above, there are the example of a destroyer and liner in order to illustrate the contrast. In each case, [2] assumed typical values for the beam and position of G, and deduce the resulting metacentric height and period of rolling ship.

Catastrophe theory then, [2] noticed that the greater metacentric height of the destroyer give a greater right couple, and hence makes her more stable, so that she can perform tighter manoeuvres, as well as causing a faster roll. [2]

By contrast, the lesser metacentric height of the liner makes her less stable, although this does not matter so much since she does not have to indulge in manoeuvres, meanwhile she increased comfort of the slower roll and smaller acceleration, which ensure that the passengers are less likely to be seasick [2].

Advantages of mathematical Catastrophe Theory are:

(i) Most complex, real world system with stochastic elements cannot be evaluated analytically, thus a simulation sometimes the only type of investigation which is possible,

(ii) a simulation is estimate the performance of an existing system under some projected set of operating conditions. Hence alternative system designs or operating policies can be compared.

(iii) In a simulation one has much better control over experimental condition than would generally be possible when experimenting with the system

(iv) A simulation allows studying the system with a long time frame.

CHAPTER 3
METHODOLOGY

3.1 Technique of Analysis

The task of developing the stability assessment method was used based on the Figure 3.1 below by representing technique of the analysis.

3.2 Execution Flow Chart

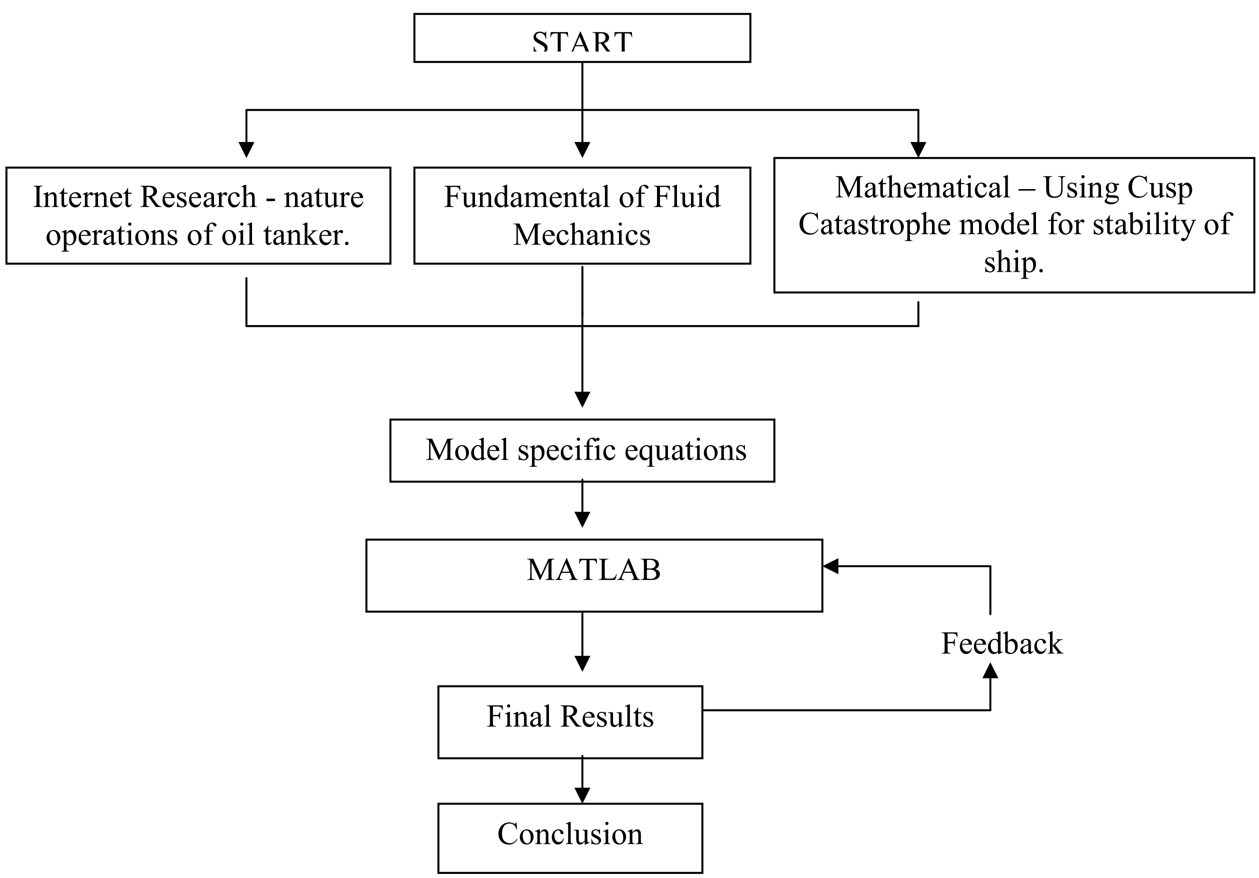


Figure 3.1: Execution flow chart

Figure 3.1 above has show about the execution flow chart during handling this project within a year. It was started with research and collecting suitable data related to the topic in order to analyze what actually we need through this project. The execution work flows were scheduled. The milestones and gant chart of the project can be referring on **Appendix 1 & 2.**

3.3 Data Gathering

3.3.1 Principal Data of Marine Boat

The data below was collected from the boat in order to check and analyze the stability on it.

Table 3.1: Principal data of Marine Boat

Principal Data	
Length Overall	16 m
Length on waterline	13.8 m
Beam Overall	4.5 m
Beam on waterline	4.06 m
Full load displacement	24 Tonnes
Draught at L/2	0.77 m
Deadrise at LCG	22 Degrees
Maximum Speed	55 Knots
Dead Norske Veritas rating	R3 Patrol

In Table 3.1, there are shown the principal data of marine boat to see what type of boat of designs favor. They are large, heavy boats with high static and dynamic stability, which will produce an easy ride with minimal crew fatigue. The calculated template terms are discussed in the following result and discussion part.

3.3.2 Mathematical Theory

Based on Figure 3.2 below, there is the Catastrophe Mathematical calculation in order to estimate the metacentric height, μ and period, T of rolling ship; an author was made very rough assumptions.

Assume:

i) Area, A of the ship is approximately rectangle with the draught to a third of the beam as shown in figure below.

Area, $A = 2a \times 2a/3 = 4a^2/3$ -------------------- (1)

Radius of curvature, $\rho = BM = 2a^3/3A = a/2$ -------------------- (2)

Meanwhile, $B = a/3$ below the waterline -------------------- (3)

$M = a/6$ above the waterline -------------------- (4)

H_1 = height of G above the waterline

Therefore, $\mu = GM = a/6 - H_1$ ------------------ (5)

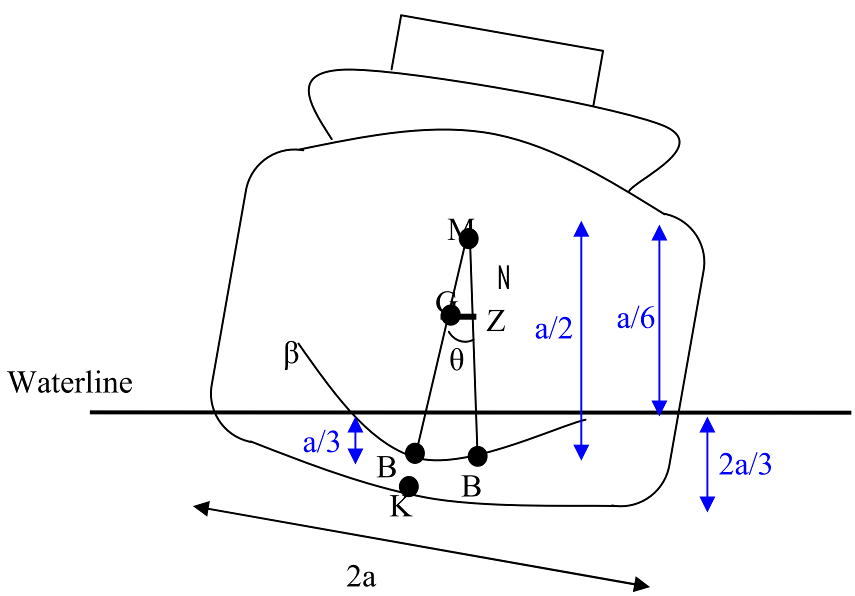


Figure 3.2: Estimate of metacentric height, μ

ii) the moment of inertia, I is the same as that of a solid disk of radius a

$$I = Wa^2/2g \qquad \text{--------------------- (6)}$$

Where g = gravitational acceleration = 9.81 m/sec^2

Thus, to compute the rolling period, T of the ship is by using,

$$T = 2\pi \sqrt{I / W\mu}$$

$$= 2\pi \sqrt{a^2/2g\mu}$$

$$= 1.42\ a/\sqrt{\mu} \qquad \text{--------------------- (7)}$$

The reason that metacentric height, GM is so important is because it is directly proportional to the amount of righting arm, GZ available.

3.4 Tools, Equipment and Software Required

For this project, the tools, equipments and software that will be used are as follows:

1. Laboratory (MATLAB)

The mathematical modeling about the stability of the oil tanker will be generated by using the software called MATLAB consecutively to obtain the necessary outputs. For example, the disturbance of the ship can be determined by the simulation of the software itself in terms of various equation required.

Some of the advantages of using MATLAB in Naval Architecture are: [5]

- the possibility of adding functions and programs written by the user;
- easy accessibility of data;
- the transparency of MATLAB programs.

The analysis will be using a simplified model of ship in rolling seas in order to study the ship's stability and find out how likely it is that the ship may capsize due to the righting arm and heel angle of the object. This MATLAB system is an example of a forced nonlinear oscillator.

CHAPTER 4
RESULTS & DISCUSSION

4.1 Results & Discussion

The results shown below are the plot of curve of statical stability. In this theoretical mathematic calculation, the simple example of stability calculation was used [9].

4.1.1 Naval Architecture Sailboat

The given displacement is Δ = 3900 t, the length between perpendiculars, Lpp = 75.95 m, the mean draft, Tm = 5.96 m, the arm of free-surface effect, FS = 0.03 m, the metacenter above baseline, KM = 5.35 m, the vertical center of gravity, KG = 4.78 m.

The data of Naval Architecture Sailboat

Table 4.1: Parameters of Naval Architecture Sailboat

Principal Data	
Length overall, L (mm)	203
Beam length, 2a (m)	17.078
Full load displacement (tonnes)	3900
Lpp (m)	75.95
Mean Draft, Tm (m)	5.96
Free surface effect,FS	0.03
KM (m)	5.35
KG (m)	4.78
Maximum speed (knots)	16

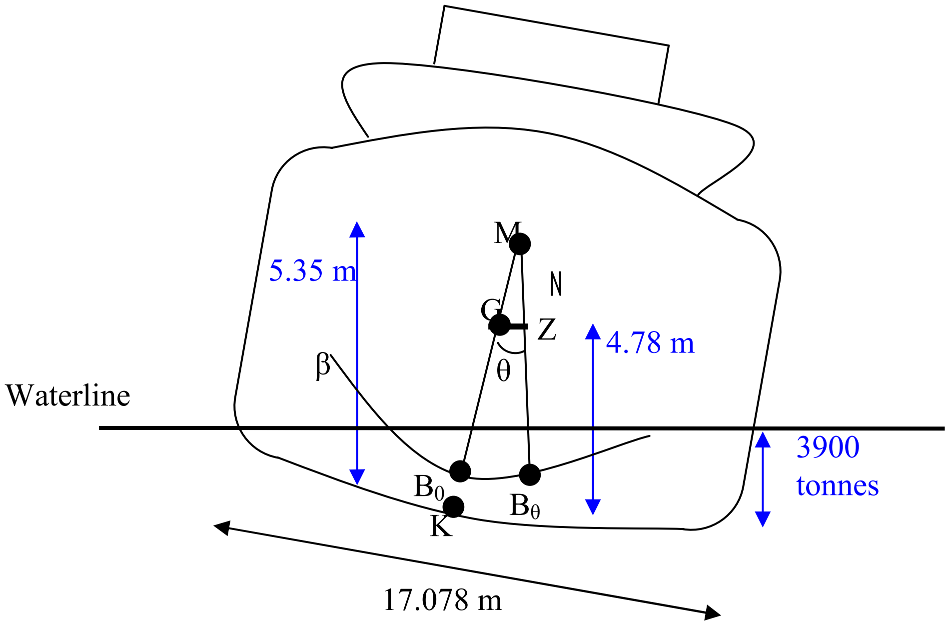


Figure 4.1: Estimate of metacentric height, GM or μ

Let B = center of gravity of the boat.

B_0 = center of buoyancy when boar floats vertically

= center of gravity of water displaced.

B_θ = center of buoyancy when boat is at angle θ.

β = buoyancy locus = $\{ B_\theta \,;\, -\pi < \theta < \pi \}$

N_θ = normal to β at B_θ.

M = metacenter = center of curvature of β at B_0.

μ = GM = metacentric height.

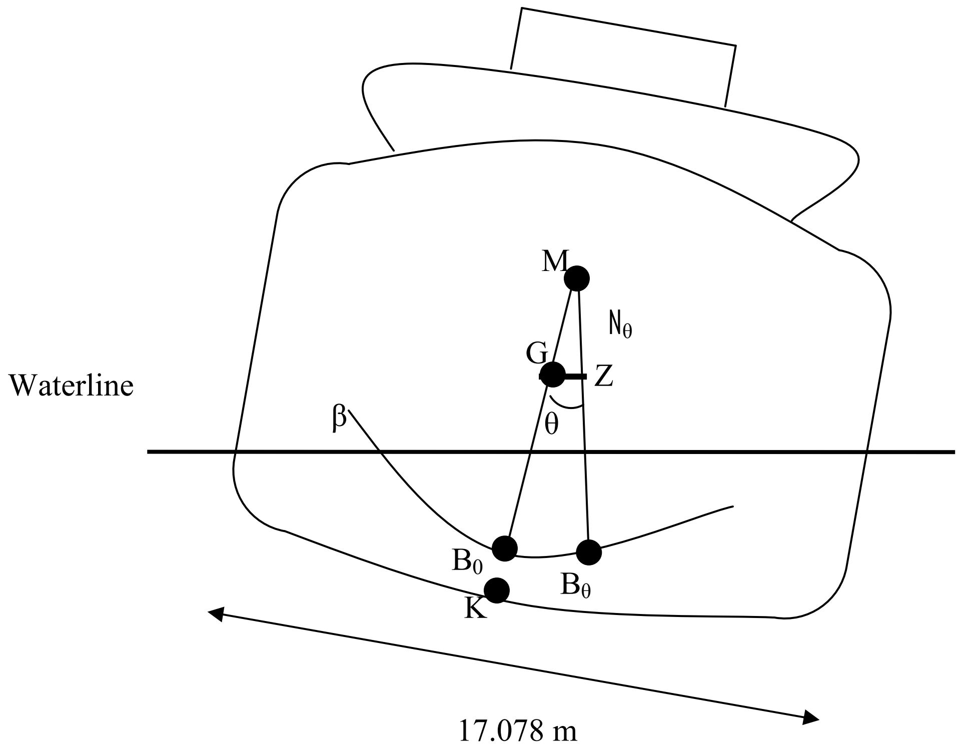


Figure 4.2: The righting couple 10º heel angle, θ.

Let GZ = £ = lever arm of this righting couple = distance from G to $N_{\theta.}$

where Z is the foot of the perpendicular from G to $N_{\theta.}$

$£_k$ = length of keel

Stability calculation for Sailboat Naval Architecture

By applying the trigonometry, thus the length of keel, $£_k$ from point K to point K_θ can be measured.

KM = 5.35 m
KG = 4.78 m

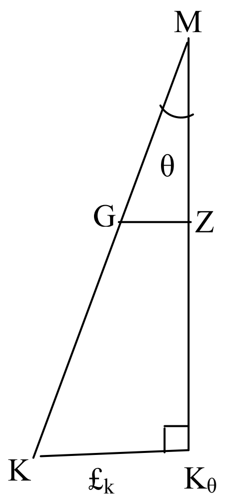


Figure 4.3: Trigonometry formed in order to find length of keel, $£_{k.}$

In order to find the keel length, $£_k$, the equation expressed as below.

$$\cos (90^o - \theta) = £_k / KM \qquad \text{-------------------- (8)}$$

Rearrange equation (8), we obtained

$$£_k = KM \cos (90^o - \theta)$$

At $\theta = 10^o$, thus;

$$£_k = 5.35 \cos (90^o - 10^o)$$

$$= 5.35 \cos 80^o$$

$$= 0.929 \text{ m}$$

The calculation keep repeating at $\theta = 20^o$, 30^o, 45^o, 60^o, 75^o, and 90^o as shown in the table 3 below.

Table 4.2: the keel length, $£_k$ with the respective heel angle degree.

Heel angle, θ^o	10	20	30	45	60	75	90
Keel length, $£_k$	0.929	1.8298	2.675	3.783	4.633	5.168	5.350

The obtaining $£_k$ can be proceed by calculate the righting arm or lever arm, GZ as shown in the figure 3.5.

The equation (9) expressed below to find GZ.

$$GZ = £_k – KG \sin \theta \qquad \text{-------------------- (9)}$$

Thus, at heel angle, $\theta = 10^o$;

$$KG \sin \theta = 4.78 \sin 10^o$$

$$= 0.83 \text{ m}$$

Since $£_k = 0.929$ m at heel angle, $\theta = 10^o$, so from equation (9),

$$GZ = £_k – KG \sin \theta$$

$$= 0.929 – 0.83$$

$$= 0.099 \text{ m}$$

The calculation keep repeating at $\theta = 20^{\circ}$, 30°, 45°, 60°, 75°, and 90° as shown in the table 4 below.

Table 4.3: the lever arm or righting arm, GZ with the respective heel angle degree

Heel angle, θ^{o}	10	20	30	45	60	75	90
Lever arm, GZ	0.099	0.195	0.285	0.403	0.493	0.548	0.570

The parameters given of the Sailboat will be used in order to estimate the rolling period of the boat. Two rough assumptions were made due to the catastrophe theory as below.

Assume:

i) Area below the waterline, A_w of the boat is approximately rectangle with the draught to a third of the beam as expressed below:

Since given beam on waterline = 2a = 17.078 m, thus a = 8.54 m. The area below waterline computed as equation (1) shown below.

$$A_w = 2a \times 2a/3 = 4a^2/3$$
$$= 17.078 \times 2(8.54)/3$$
$$= 97.23 \text{ m}^2$$

While the radius of curvature, BM as in equation (2) computing as below.

$$\rho = B_0M = 2a^3/3A_w = a/2$$
$$= 2(8.54)^3 / 3(97.23)$$
$$= 4.2705 \text{ m}$$

Meanwhile, referring on figure 3.4 above, center of buoyancy, B_0 , metacenter point, M and H_1 are also will be estimated as equation (3) shown below.

$$B_0 = a/3 \text{ below the waterline}$$
$$= 8.54 / 3$$
$$= 2.847 \text{ m}$$

From equation (4),

$$M = a/6 \text{ above the waterline}$$
$$= 8.54 / 6$$
$$= 1.423 \text{ m}$$

Since the center of gravity, G is measured by the shape of the hull boat, thus G is fixed. Thus, H_1 point is the height of G above the waterline.

Therefore, from equation (5),

$$\mu = GM = a/6 - \mathbf{H_1}$$

where $GM = KM - KG$

$$= 5.35 \text{ m} - 4.78 \text{ m}$$
$$= 0.57 \text{ m}$$

H_1 = height of G above the waterline

$$= a/6 - GM$$
$$= 1.423 \text{ m} - 0.57 \text{ m}$$
$$= 0.853 \text{ m}$$

ii) the moment of inertia, I as equation (6) is the same as that of a solid disk of radius beam, a

$$I = Wa^2/2g$$

where g = gravitational acceleration = 9.81 m/sec^2

From the equation (6), moment of inertia computed as below,

$$I = Wa^2/2g$$
$$= (3900\text{tonne} \times 1000\text{kg/tonne})(8.54)^2 / 2(9.81)$$
$$= 1.057 \times 10^9 \text{ kg.m/sec}^2$$

Thus, to compute the rolling period, T of the ship is by using equation (7) as below,

$$T = 2\pi \sqrt{I / W\mu}$$
$$= 2\pi \sqrt{a^2/2g\mu}$$
$$= 1.42a / \sqrt{\mu}$$

From equation (7), the roll of period is

$$T = 1.42(8.54) / \sqrt{0.57}$$

$$= 16.06 \text{ sec}$$

Matlab Code Listing

```
Command Window
>> KM=5.35;
>> KG=4.78;
>> FS=0.03;
>> heel=[0 10 20 30 45 60 75 90];
>> lk=[0 0.936 1.823 2.610 3.708 4.540 4.931 4.9431];

>> GZ=lk-KG*sind(heel);
>> heeli= 0:5:90;
>> GZi=spline(heel, GZ, heeli);
>> plot(heeli, GZi, 'k-'), grid
>> title('\Delta=3900 t, KG=4.78 m')
>> xlabel('heel angle, degrees')
>> ylabel('lever arms')
>> hold on
```

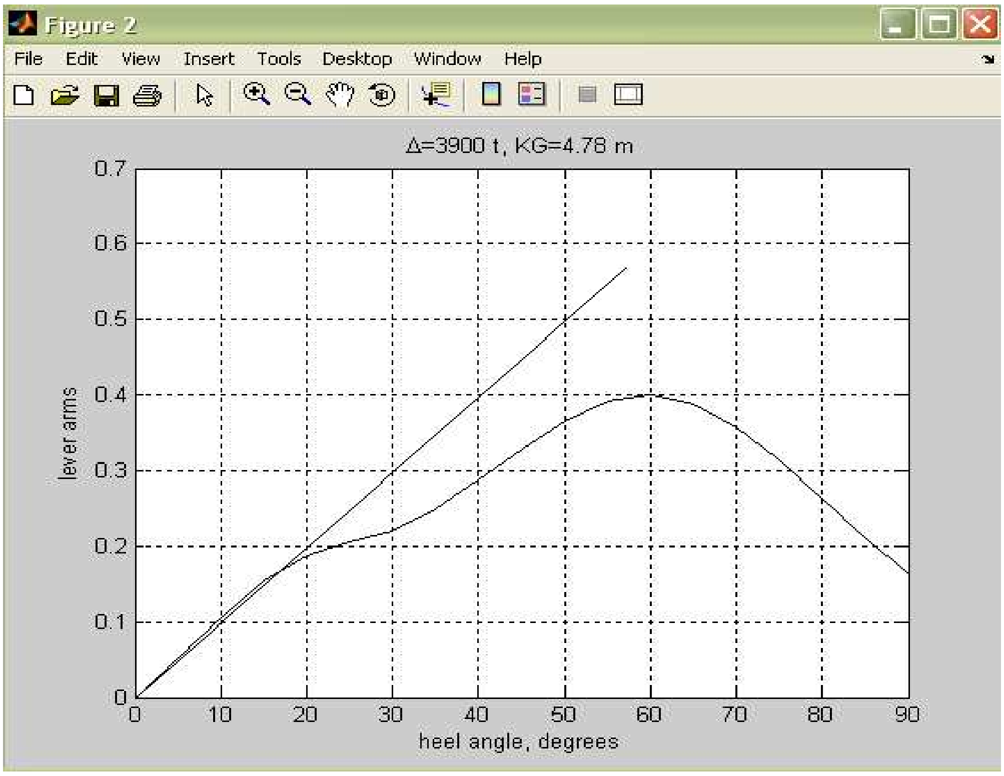


Figure 4.4: The righting arm, GZ calculation

The horizontal displacement is called the righting arm and its use to the righting moment. As the nature phenomenon, such as wave lead a ship to heel. Thus, the righting-arm shown in Figure 4.4 expressed as a function of heel angle affect of the ship will return to the vertical equilibrium condition.

```
>> GM=KM-KG;
>> plot([0 180/pi], [0 GM], 'k-')
```

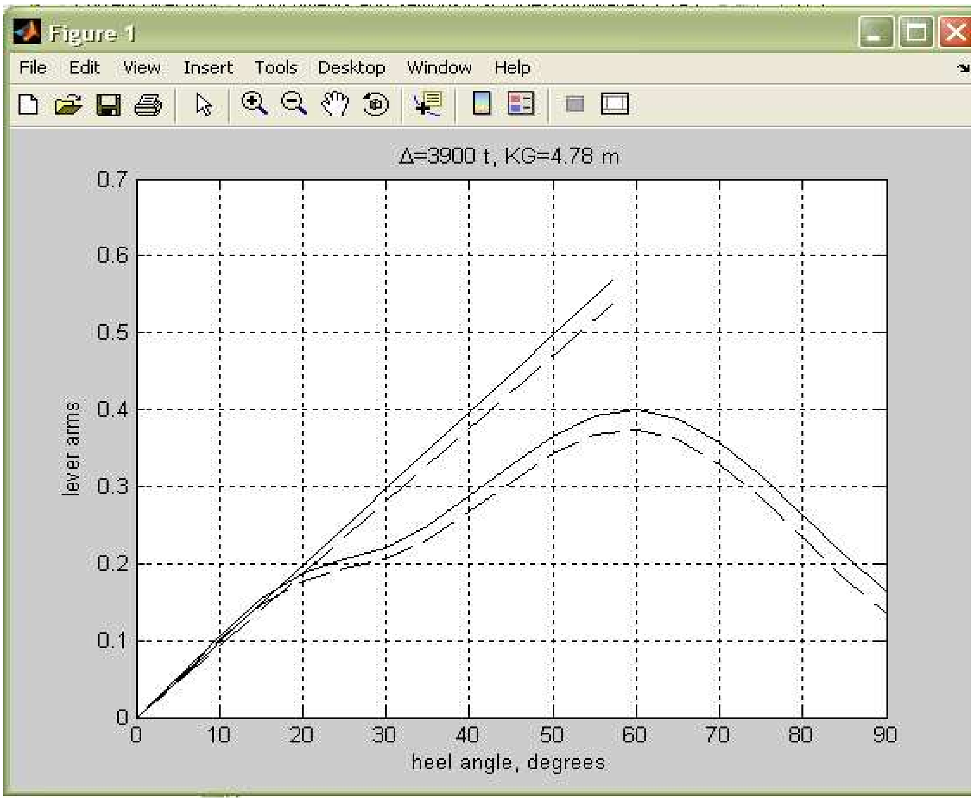


Figure 4.5: The metacentric height,GM calculation

Based on the Figure 4.5 above, the metacentric height was calculated a line plotted with one x-coordinate in the origin, 0. (Black as a solid line)

The Figure 4.5 above has shown the metacentric height increasing gradually due to heel angle. The larger the metacentric height the more stable is the ship. However, the larger the metacentric height the shorter is the period of roll, and the more uncomfortable is the ship (heel angle degree reduced), therefore choices of estimate metacentric height,μ is an important features of ship design.

```
>> GZeff=GZi-FS*sind(heeli);
>> plot(heeli, GZeff, 'k--')
>> GMeff=GM-FS;
>> plot([0 180/pi], [0 GMeff], 'k--')
>> V0=0.5144*16;
>> lT=0.02*(V0^2/Lpp)*(KG-Tm/2)*cosd(heeli);
>> plot(heeli, lT, 'r-')
>> [phi_st GZst]=ginput(1)

phi_st =

    3.4217


GZst =

    0.0317

>> hold off
>>
```

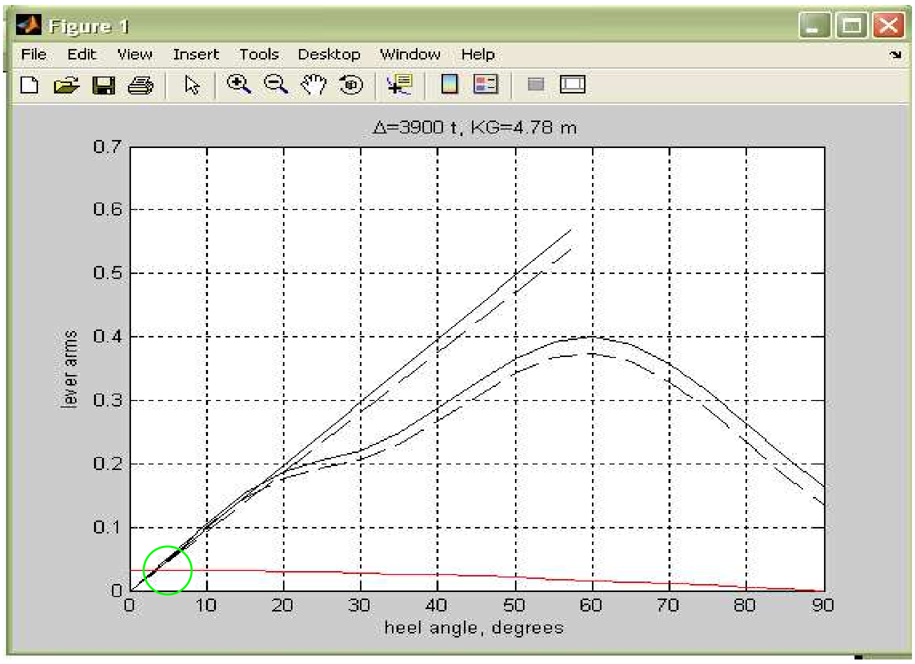


Figure 4.6: The efficient of righting-arm and metacentric height in dash line. While the red line express the heeling-arm in turning curve over the curve of statical stability. [0º < θ < 90º]

Based on the Figure 4.6 above, visually the value of the angle of statical stability is 3.42 degree, at the intersection of the turning heeling arm and righting-arm.

4.1.2 Perlis Marine Boat

As shown below, there is a empirical experimental did on the existed marine boat. Throughout the MATLAB simulation, the data collected as shown:

An empirical data of Perlis Marine Boat

Table 4.4: Parameter of Perlis Marine Boat

Principal Data	
Length Overall, L (m)	16
Length on waterline (m)	13.8
Beam Overall (m)	4.5
Beam on waterline, 2a (m)	4.06
Full load displacement (tones)	24
Draught at L/2 (m)	0.77
Deadrise at LCG (º)	22
Maximum Speed, V (knots)	55
Dead Norske Veritas rating	R3 Patrol

In Table 4.4, there are shown the principal data of marine boat to see what type of boat of designs favor. They are large, heavy boats with high static and dynamic stability, which will produce an easy ride with minimal crew fatigue.

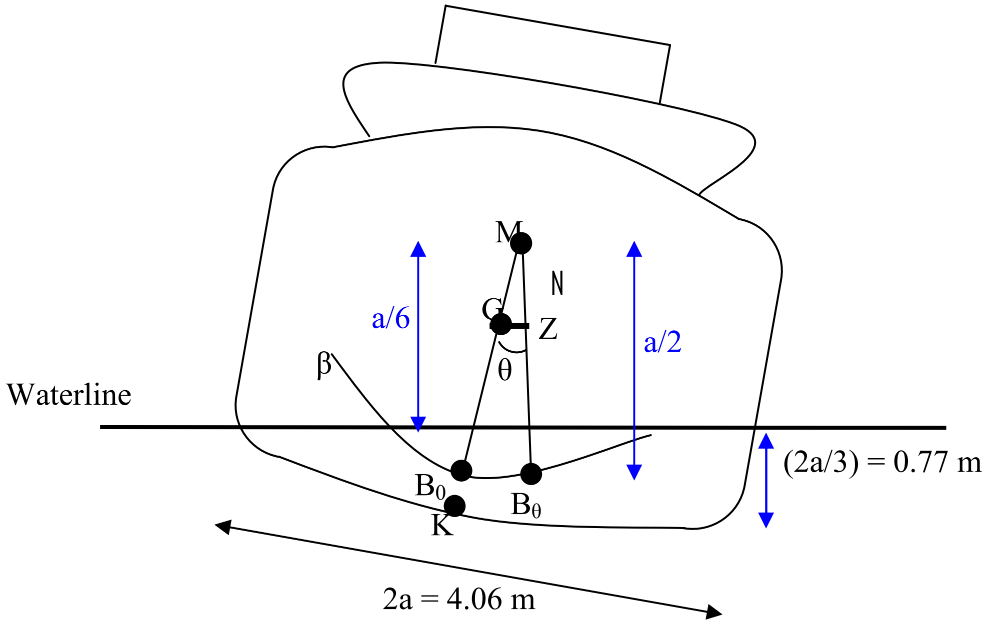


Figure 4.7: Estimate of metacentric height, GM or μ

Let B = center of gravity of the boat.

B_0 = center of buoyancy when boat floats vertically

= center of gravity of water displaced.

B_θ = center of buoyancy when boat is at angle θ.

β = buoyancy locus = { B_θ ; $-\pi < \theta < \pi$ }

N_θ = normal to β at B_θ.

M = metacenter = center of curvature of β at B_0.

μ = GM = metacentric height.

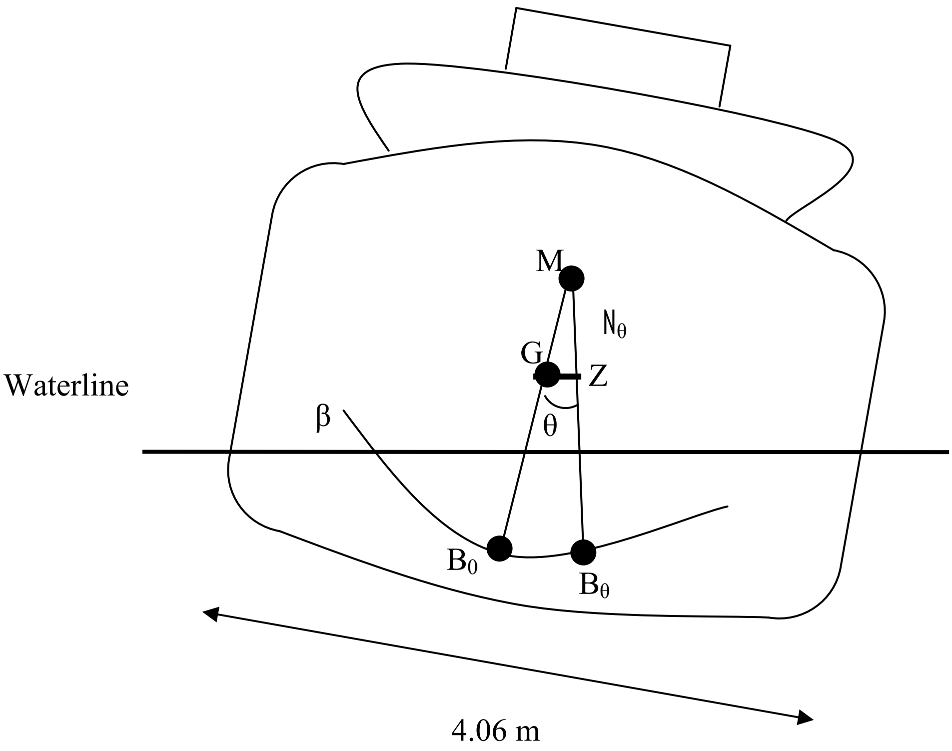


Figure 4.8: The heel angle, θ at 10º.

The figure 4.8 above has shown when boat at 10 º heel angle, θ, and the normal, N_θ is vertical. Besides, there is righting couple consists of weight, W of the boat acting downward at G, and the buoyancy force acting upward at B_θ.

Let GZ = £ = lever arm of this righting couple = distance from G to N_θ.
where Z is the foot of the perpendicular from G to N_θ

ρ = BM = radius of curvature

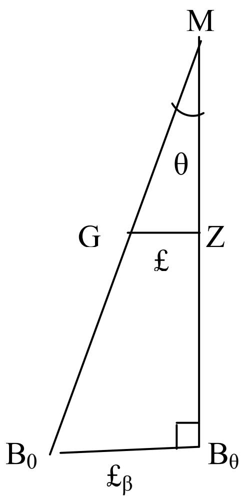


Figure 4.9: Trigonometry triangle in order to estimate the lever arm, GZ.

The parameters given of the Marine Boat in Table 4.4 will be used in order to estimate the metacentric height, GM or μ. It is depends on the rolling period of the boat. Two rough assumptions were made due to the catastrophe theory as below.

Assume:

i) Area below the waterline, A_w of the boat is approximately rectangle with the draught to a third of the beam as expressed below:

Since given beam on waterline = 2a = 4.06 m, thus a = 2.03 m. The area below waterline computed as equation (1) as below.

$$A_w = 2a \times 2a/3 = 4a^2/3$$
$$= 4.06 \times 2(2.03)/3 = 5.495 \text{ m}$$

While the radius of curvature, BM as in equation (2) as below,

$$\rho = B_0M = 2a^3/3A_w = a/2$$
$$= 2(2.03)^3 / 3(5.495)$$
$$= 1.015 \text{ m}$$

Meanwhile, referring on figure 3.4 above, center of buoyancy, B_0 , metacenter point, M and H_1 are also will be estimated as equation (3) shown below.

$$B_0 = a/3 \text{ below the waterline}$$
$$= 2.03 / 3$$
$$= 0.677 \text{ m}$$

From equation (4),

$$M = a/6 \text{ above the waterline}$$
$$= 2.03 / 6$$
$$= 0.338 \text{ m}$$

Since the center of gravity, G is measured by the shape of the hull boat, thus G is fixed. Thus, H_1 point is the height of G above the waterline.

$$\mathbf{H_1 = height\ of\ G\ above\ the\ waterline}$$
$$= 0.12 \text{ m}$$

Therefore, as in equation (5),

$$\mu = GM = a/6 - \mathbf{H_1}$$
$$= 0.338 - 0.12$$
$$= 0.218 \text{ m}$$

ii) the moment of inertia, I as shown in equation (6) is the same as that of a solid disk of radius beam, a

$$I = Wa^2/2g$$

where g = gravitational acceleration = 9.81 m/sec^2

From the equation (6), moment of inertia computed as below,

$$I = Wa^2/2g$$
$$= (24\text{tonne} \times 1000\text{kg/tonne})(2.03)^2 / 2(9.81)$$
$$= 5{,}040.86 \text{ kg.m/sec}^2$$

From equation (7), the roll of period is

$$T = 1.42(2.03) / \sqrt{0.218}$$
$$= 6.174 \text{ sec}$$

After several parameter were assumed, due to the figure 3.6 which is the trigonometry triangle is using to determine the length of curvature, $£_\beta$ and lever arms, £ respectively. Since $B_0M = 1.015$ m, thus we can calculate $£_\beta$ at heel angle, $\theta = 10^o$.

Using equation (8), thus at heel angle 10^o,

$$£_\beta = B_0M \sin\theta$$
$$= 1.015 \sin 10^o$$
$$= 0.176 \text{ m}$$

The calculation keep repeating at $\theta = 20\,^{o}$, $30\,^{o}$, $45\,^{o}$, $60\,^{o}$, $75\,^{o}$, and $90\,^{o}$ as shown in the table 3 below.

Table 4.5: the curve length, $£_{\beta}$ with the respective heel angle degree.

Heel angle, θ^{o}	10	20	30	45	60	75	90
Keel length, $£_{\beta}$	0.176	0.347	0.508	0.718	0.879	0.980	1.015

The obtaining $£_{\beta}$ can be proceed by calculate the righting arm or lever arm, GZ as shown in the figure 3.6.

Used equation (9) as below to find GZ

$$GZ = £_{\beta} - B_0G \sin\theta$$

At heel angle, $\theta = 10^{o}$ and $B_0G = 0.787$ m;

$$B_0G \sin\theta = 0.787 \sin 10^{o}$$

$$= 0.137 \text{ m}$$

Thus, since $£_{\beta} = 0.176$ m at heel angle, $\theta = 10^{o}$, so from equation (9),

$$GZ = £_{\beta} - B_0G \sin\theta$$

$$= 0.176 - 0.137$$

$$= 0.039 \text{ m}$$

The calculation keep repeating at $\theta = 20\,^{o}$, $30\,^{o}$, $45\,^{o}$, $60\,^{o}$, $75\,^{o}$, and $90\,^{o}$ as shown in the table 4 below.

Table 4.6: the lever arm or righting arm, GZ with the respective heel angle degree

Heel angle, θ^{o}	10	20	30	45	60	75	90
Lever arm, GZ	0.039	0.078	0.114	0.162	0.197	0.22	0.228

Matlab Code Listing

Command Window

```
>> Lpp=16;
>> Tm=0.77;
>> Disp=24;
>> BM = 1.015;
>> BG = 0.787;
>> FS=0.03;
>> heel=[0 10 20 30 45 60 75 90];
>> lB=[0 0.176 0.347 0.508 0.718 0.879 0.98 1.015];
>> GZ = lB - BG*sind(heel);
>> heeli= 0:5:90;
>> GZi=spline(heel, GZ, heeli);
>> plot(heeli, GZi, 'k-'), grid
>> title('\Delta = 24 t, BG = 0.787 m');
>> xlabel('Heel angle, degrees')
>> ylabel('Righting arms')
>> hold on
>> GM = BM - BG;
>> plot([0 180/pi], [0 GM], 'k-')
>> GZeff=GZi - FS*sind(heeli);
>> plot(heeli, GZeff, 'k--')
>> GMeff = GM - FS;
>> plot([0 180/pi], [0 GMeff], 'k--')
>> v0=0.5144*55;
>> lT=0.02*(v0^2/Lpp)*(BG-Tm/2)*cosd(heeli);
>> plot(heeli, lT, 'r-')
>> [phi_st GZst] = ginput(1)

phi_st =

   60.0346


GZst =

    0.1993
```

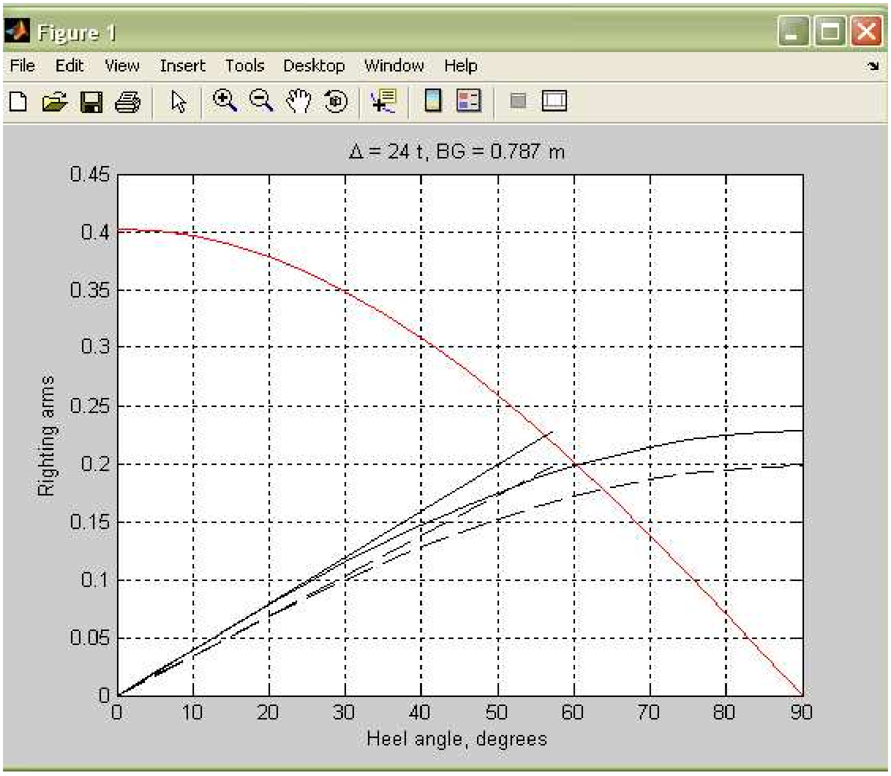


Figure 4.10: The righting arm, GZ and metacentric height, GM calculation

[$0^{\circ} < \theta < 90^{\circ}$]

The Figure 4.10 above shown that the calculation of the righting-arm as a function of heel angle affect of the boat will return to the vertical equilibrium condition and for the straight line shown the metacentric height, GM that had been calculated.

Based on the figure 4.10 above, the metacentric height is increasing gradually to heel angle curve. The higher the metacentric height the more stable is the marine boat. However, the higher the metacentric height the shorter is the period of roll, and can avoid the marine boat lead to capsize because the decreasingly degree of heel angle.

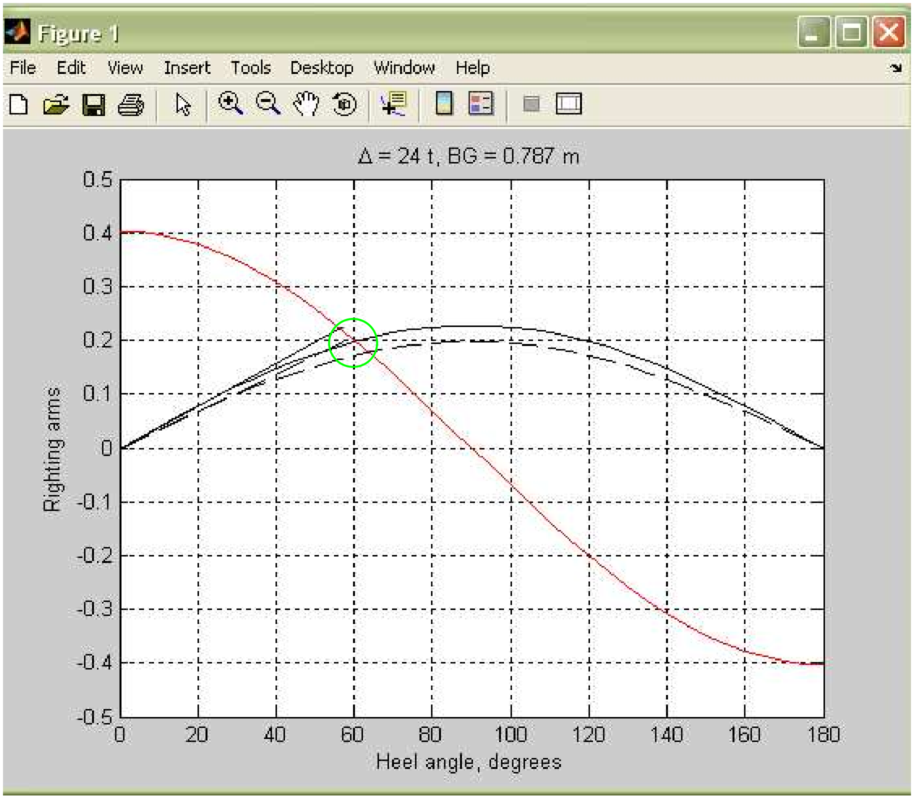


Figure 4.11: The efficient of righting-arm and metacentric height in dash line. While the red line express the heeling-arm in turning curve over the curve of statically stability. [0º < θ < 180º]

Based on the Figure 4.11 above, visually the value of the angle of statical stability is 60 degree, at the intersection of the turning heeling arm and righting-arm. The heeling arms are dependant on the displacement of the vessel. This means that the heeling arm will vary with the displacement or righting arm. **See Appendix 4**

When evaluating these criteria that are dependent on displacement, care has to be taken to make sure any change in displacement is taken into account. For large angle stability this means that every loadcase will have its own set of criteria.

CHAPTER 5
CONCLUSION & RECOMMENDATION

5.1 Conclusion

As the conclusion, the naval architectural computer programs are normally used in conjunction with official submittals. These programs very accurately calculate distance values of keel to buoyancy, KB, metacentric radius, BM, and keel to metacentric, KM in order to calculate term GM which is extremely important and it is called the metacentric height of a vessel. For a vessel to be stable the numerical value of GM must be positive. This means that G must always be located below M. They also generate other important and often required stability data like Lines Drawings, Curves of Form, Cross Curves of Stability, and Curves of Statical Stability as shown in Figure 4.6.

Metacentric height is a very useful index of ship's stability. Its used in this context is based on the assumption that adequate GM or/conjunction with adequate freeboard will assume that sufficient righting moments exist at any practical angle of heel.
A large GM gives a large righting arm. This mean a ship will snap back from a roll quickly but will also roll easily. This gives a violent motion. Too fast a roll will swamp the freeboard quickly.
In contrast, a low GM gives a small righting arm which means the ship will roll slowly but return even more slowly. Reducing seasick for passenger but may cause a dangerous position in heavy weather.

Static stability was primarily discussed and to be applied as opposed to dynamic stability. Dynamic stability involves righting arms over a large range of heel angles. This type of analysis involves quantification of volumetric centers of heeled displacement volumes. Dynamic stability is also important because it is a measure of a vessels ability to withstand the effects of wind and waves (catastrophe phenomenon).

5.2 Recommendation

By the way, GM is only the indicator. To determine the stability of a ship accurately, the designers have to do inclining tests, deliberately listing the ship to varying angles then doing strings of calculation. This often reveals some nasty surprises.

For the vessel, it will have:

1. Positive stability if the metacenter is above the center of gravity. **See Appendix 3.1**
2. Indifferent stability if the metacenter coincides with the center of gravity, in which case there is no righting lever to restore the original position.
3. Negative stability if the metacenter is below the center of gravity with risk of capsizing. **See Appendix 3.3**

If the metacentric height exceeds the normal limited the vessel will be stiff and will roll heavily in bad weather at very short intervals, subjecting the ship to heavy strain, which may cause damage to the ship's structure apart from the risk of shifting of cargo through excessive rolling.

On the other hand if the metacenter height is too small the ship will be tender, which may cause a dangerous position in heavy weather.

Vessels sailing in ballast will have a very low center of gravity when all double bottom tanks and deeptanks are filled to capacity and no ballast is carried in the uppertweendecks or on deck, which will raise the center of gravity. It is a question of right disposition of ballast.

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APPENDIXES

Gant Chart / Milestone

Appendix 1: Gant chart / milestone of FYP I

No.	Activities	Week No / Date													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of the Project Topic														
2	Preliminary Research Work														
3	Submission of Preliminary Report					21/8									
4	Project Work														
5	Submission of Progress Report								8/9						
6	Seminar								11/9						
7	Project Work Continues														
8	Submission of Interim Report Final Draft														26/10
9	Oral Presentation										2/11 - 13/11				

Appendix 2: Gant Chart / Milestone of FYP II

		Week No / Date														
No.	**Activities**	**1**	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Project works															
2	Progress Report 1					22/2										
3	Project Work															
4	Progress Report 2								mid	22/3						
5	Seminar								sem	22/3 - 26/3						
6	Project work															
7	Poster Submission												12/4			
8	Dissertation Final Draft															3/5
9	Oral Presentation												study		week	
10	Hardbound Dissertation															20/5

Appendix 3: Metracentric Height

This expression may be explained best by the following figures:

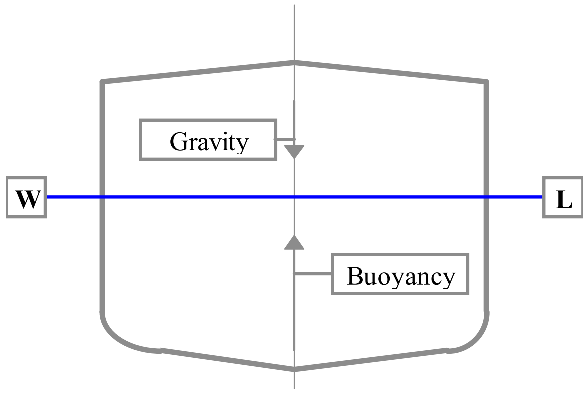

Figure A3.1

The ship, loaded down to her marks, is lying in still water without list.

WL =	Water line
G =	Center of Gravity
B =	Center of Buoyancy of water displaced by the ship.

G and B are lying in the same vertical plane amibships.

The ship is in stable equilibrium. The upward pressure acting through B is equal to the weight of the ship acting downward through G.

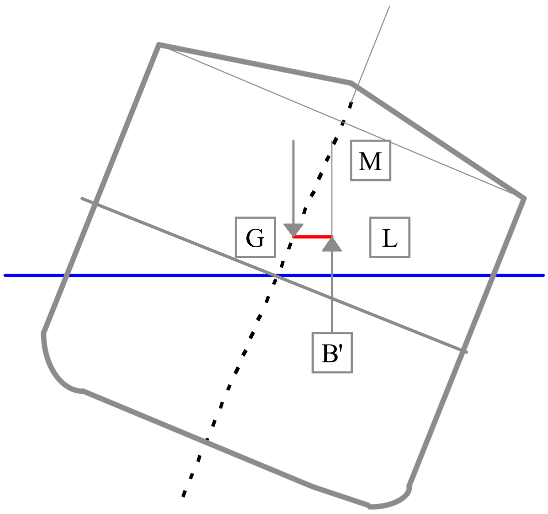

Figure A3.2

The ship has rolled to one side through external force and has got a slight list.

WL = Water Line

G = Center of Gravity. The position of G has not changed, assuming the cargo has not shifted.

B' = New position of center of buoyancy. Owing to the change of the immersed part of the ship, the position of B has shifted to the lower side (B').

M = Metacenter, being the point of intersection of the perpendicular line drawn from B' and the plane amidships.

MG = Metacentric Height

GL = the righting lever, tending to return the ship to her original position of stable equilibrium.

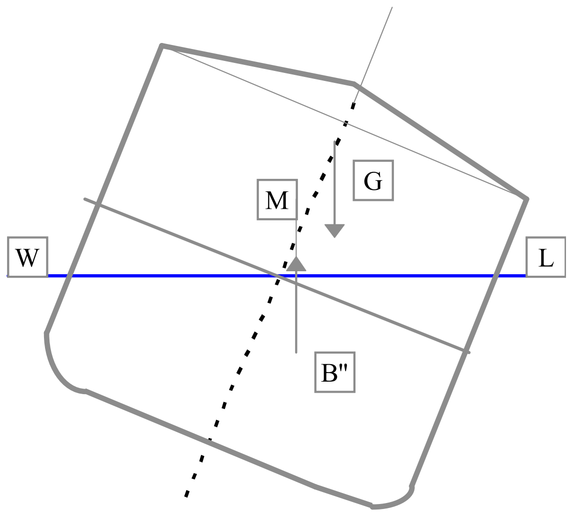

Figure A3.3

The position of G is higher, which may result from empty double bottom tanks, stowage of cargo in the uppertweendecks etc. Through external force the vessel has got a list.

WL = Water Line

G = Center of Gravity

B" = Center of Buoyancy

There is no righting lever to return the ship to her normal position; on the contrary the ship is top-heavy.

Summarizing the center of gravity of ship, cargo, water, bunkers, stores and equipment must always be below the metacenter. Under normal circumstances the metacenter height (MG) for vessels loaded with a homogeneous cargo down to her marks will be at least 12 inches.

Appendix 4: Turning Heeling Arm

The magnitude of the heel arm is derived from the moment created by the centripetal force acting on the vessel during a high-speed turn and the vertical separation of the centres of gravity and hydrodynamic lateral resistance to the turn. The heeling arm is obtained by dividing the heeling moment by the vessel weight. The heeling arm is thus given by:

$$H_t(\phi) = a\frac{v^2}{Rg}h\cos^n(\phi)$$

where (in consistent units):

a is a constant, theoretically unity

v is the vessel velocity

R is the radius of the turn

h is the vertical separation of the centres of gravity and lateral resistance

The heeling arm parameters are specified as follows:

Option	Description	Units
constant: a	Constant which may be used to modify the magnitude of the heel arm, normally unity	none
vessel speed: v	Vessel speed in turn	length/time
turn radius: R	Turn radius may be specified directly	length
turn radius, R, as percentage of L_{WL}	Or, as some criteria require, as percentage of L_{WL}	%
Vertical lever: h	There are four options for specifying h (all options are calculated with the vessel upright at the loadcase displacement and LCG): User specified	length
h = KG	h is taken as KG - position of G above baseline in upright condition	length
h = KG - mean draft / 2	h is taken as KG less half the mean draft.	length
h = KG - vert. centre of projected lat. u'water area	h is taken as the vertical separation of the centres of gravity and underwater lateral projected area.	length
cosine power: n	Cosine power for curve - defines shape	none