Capsizing of Ships: Static and Dynamic Analysis of Wind Effect and Cost implications

by
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And
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ABSTRACT

Capsizing of small vessels, such as commercial fishing vessels, is a frequent event. This phenomenon is generally associated with the combined action of storm seas, inadequate design parameter regulations, and dangerous operational procedures. In contrast, the capsizing of large ships is rare, but does occur. For these large vessels, more strict regulations exist to ensure safe operational procedures. While the storminess of the sea cannot be controlled, the navigation procedure can. Large offshore ships tend to navigate in a path to avoid forecasted severe weather, and in cases of stormy seas they temporarily operate at safe speeds and in the direction parallel to the waves.

The work presented in this thesis investigates the effect of the wind in rolling and finally capsizing a ship. For the purposes of mechanical analysis, realistic hull forms are used and fundamental issues associated with moments and forces imposed by the wind, are applied. The platforms are examined for several wind speeds that strike the ship at different angles. Both static and dynamic cases were examined. Under the assumption of general conditions, the angles of heeling in each case and the wind speeds that caused the ship to capsize are calculated.

Furthermore, a cost analysis associated with the total loss of the ship due to capsize is also reviewed. An existing worldwide database of vessel total losses, dating from 1960 to present, is used to calculate the costs per ship capsize. Some simplifications are inevitably used, because the cost implications of total ship losses have both direct and indirect portions that are difficult to quantify. In addition, the actual numbers that result from such a catastrophe are not generally available to the public and are not found in the open literature. Given these limitations, a preliminary analysis of the capsize-associated costs is performed for several types of commercial vessels.

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Finally I would like to thank my friend, Georgios Constantinidis and my co-partner Marianne Holt-Phoenix whose reviewing and commenting was very helpful to me.

This work is dedicated to the memory of my father, Antonios, whose efforts and principles guided me through all my life. Also, it is dedicated to my mother, Eleni, and my brother, Haris, whose existence fill up my life

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Chapter 1: Introduction

1.1. *Problem Statement*

Traveling at sea can result in casualties that lead to loss of life and money. Furthermore, in many occasions, maritime accidents can lead to serious environmental pollution. Fire, explosion, collision, grounding, and/or machinery breakdown are the main causes of ship capsize and eventual sinkage, primarily due to loss of stability through reduction of reserve buoyancy.

Human factor is considered the most important cause of casualties at sea. This is usually encountered in the form of underestimation of several environmental conditions and ignorance of safety rules. Nobody can however ignore the significant role of the environmental conditions that a ship will face. Fog for example is an important factor that lowers the visibility and in many cases led to grounding or collision. Despite the many advances made in the area of radar and other electronic navigational aids, collisions and groundings continue to occur every year. It is hoped, however, that technological advances will in the near future reduce such occurrences.

Among the environmental factors that can cause capsizing of a ship or a boat, extreme weather conditions are dominant. In particular, the combined effect of wind and waves can lead to an excess roll angle, water on deck, or motion of the cargo. This vicious circle of chain events can eventually drive the ship to capsize. Unfortunately, the capsize mechanism has not yet be fully understood due to the underlying complex dynamics and parameters. Despite today's advanced technology, it is not yet feasible to design and construct capsizing-resistant ships. The reason lies in the fact that it is not possible to model and simulate nature mathematically with all its aspects. Thus, the random, unpredictable, and sometimes chaotic character of ocean environment is responsible for capsizes and loss of life.

Studying the causes of capsizing in more detail, understanding the nature of waves and winds blowing over them, and finding the forces and moments that these conditions apply on the ship will contribute to a better understanding of capsizing phenomena. It is the intention of this thesis to contribute to the knowledge that can lead to the design of safer ships and the critical examination of existing vessels against capsizing.

1.2. *Thesis Outline*

The aim of this document is to predict the roll angle that ships of a given hull form will suffer when subjected to winds of different velocities and angles of attack. In addition, this document will study the human reliability factor when decisions have to be made in order to avoid the capsizing danger when a heavy weather condition has been announced. Special attention is given to:

- theoretical background on which wind effects are quantified

- description of most important elements in each step of the prediction procedure
- major assumptions made and the limits of applicability
- sensitivity of ship performance on the related parameters

This thesis is composed of six Chapters. The first Chapter deals with the presentation of the topic. Chapter 2 describes the theoretical background required to further investigate capsizing in ships. In particular it details the mechanisms of capsizing, the ship stability analysis, the generation of statical stability curves and how they are influenced by ship geometry (hull form).

Chapter 3 deals with the wind effect on hull. The three selected hull forms are tested under the influence of winds. The mathematical equations describing this phenomenon are developed and the theoretical predictions are presented. The effect of the wind striking the ship with different velocities and angles of attack during static and dynamic processes is investigated. The roll angle is calculated in all cases and conditions under which capsizing occurs are found.

Chapter 4 details the results obtained by the analytical formulation developed in Chapter 3. In order to properly solve the dynamic problem, initial boundary conditions are imposed. Apart from the case that the initial conditions are zero the chapter also includes calculations for the cases where non-zero initial conditions are experienced.

Chapter 5 summarizes the main assumptions made in this thesis and suggests potential routes for future refinements and increased accuracy.

Chapter 6 discusses the economic aspects of capsizing for several types of ships.

Chapter 2: Theoretical Background

The purpose of this chapter is to give to the reader a quick general idea of some of the theoretical principles and background needed for the evaluation procedure that follows. All these theoretical aspects can be found in more details in any good naval architecture text.

2.1. Mechanisms of capsizing

The dominant cause of small ship capsizing is the combined action of breaking waves with excess magnitude winds blowing over them. Historical evidence suggests that small boats are more vulnerable to capsize due to breaking waves than large boats. In fact, capsizing of a vessel over 100 feet is very rare.

There are several mechanisms that can lead to capsize, some of which will be detailed below. Most of these mechanisms are essentially non-linear in nature and they cannot be investigated by a simple frequency-domain approach. One mechanism that can cause capsize involves static stability characteristics. In following or quartering seas, the wave-encountered frequencies are much lower than in head seas or seas on the bow, which means that the wave profile is almost stationary relative to the ship. As a consequence, the ship may become statically unstable in roll, relative to the waterline defined by the wave profile. This happens because the wave surface is not plane and neither is the instantaneous load waterline. The metacentric radius BM_T which is derived for this modified waterline may in fact differ from that computed for the still waterline. The metacentric height, GM_T, is very sensitive to the metacentric radius and as a consequence significant variations in GM_T can occur with frequencies equal to the encountered frequency. This parametric change of GM_T can lead to roll instabilities, with roll motions increasing in time. This effect is amplified for ships with low initial stability.

A different mechanism which can cause a ship to capsize, is a phenomenon called broaching. As a term, broaching, describes the situation in which a ship veers broadside to the wind and waves. This can be caused when the frequency of the encounter between the ship and the waves is small. The result is an altered course relative to the waves. This situation can lead to large amplitude of the unrestored motions of sway and yaw, which result in serious interactions with the steering and large resonant roll angles. In cases of extreme high waves and excess magnitude of winds, where the water particle velocities become comparable to the ship speed, the broaching mechanism may force the ship to yaw to an orientation parallel to the wave crest, which is extremely dangerous and may eventually lead to capsizing.

2.2. *Stability Curves Inadequacy*

In order to investigate the safety of the ship-stability one needs to study its static and dynamic response under the effect of moments applied to the ship by winds and waves (or any other reason than can cause a heeling to the ship). The conventional statical stability analysis of ships is well known and simply presented by the righting arms (RA) curve. Unfortunately, the existing stability standards do not demand rigorous analysis of wave and wind forces that, often, are the main causes of capsizing. Various characteristics of the RA curve, such as the initial metacentric height, GM, angle of vanishing stability, and area under the curve are directly dependent upon ship's hull form and weight distribution. This type of analysis should be extended a step further to include the effect of external disturbing forces by wind.

2.3. *Floating Body Principles and Righting arm*

To proceed to the wind effect analysis it is necessary to give a short introduction to the theoretical background of the ship stability. In particular, this section describes the importance of righting arms, the way that they are related to the angle of heel and their utilization for the following calculations.

It is known that a ship, as any afloat body, experiences the force of buoyancy equal to the weight of the displaced liquid. The resultant of that force is acting vertically upward through a point called the center of buoyancy (B), which is the center of gravity of the displaced liquid. The application of this principle to a ship makes it possible to evaluate the hydrostatic pressure acting on the hull and the appendages by determining the volume of the ship below the waterline and consequently its centroid. This volume, when converted to weight, is called displacement (Δ).

The behavior of a floating object is determined by the interaction of the forces of the weight and buoyancy. In the absence of any other forces, and in the case of positive stability the ship will settle until the force of buoyancy equals the weight and it will rotate until the two following condition is satisfied, as shown in Figure 1[1]:

a. The centers of buoyancy B and gravity G are in a vertical line, and
b. Any slight rotation from this position from an initial waterline to another will cause the equal forces of weight and buoyancy to generate a restoring couple which tends to move the ship back to float on the initial waterline

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[1] Principles of Naval Architecture Volume I pp. 64

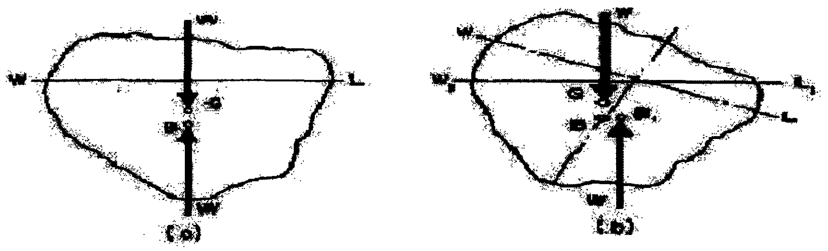

Figure 1: Equilibrium of floating body

For every stable object there is at least one position at which the above conditions are satisfied. Any deviation from that position would produce a moment tending to restore the body to the initial position. These moments are called *righting moments.* Depending on the vertical position of the center of gravity, G, either righting moments which oppose further inclination or upsetting moments which contribute to continued inclination and potential capsize.

Lowering the center of gravity will increase stability. This happens because when a righting arm exists, lowering the center of gravity increases the separation of the two forces and thus increases the righting moment. When a heeling moment exists, lowering the center of gravity would change the heeling moment to a righting one. All the above are schematically shown in Figure 2[2]. To better understand the following figure, one needs to investigate how the righting arms change as the center of gravity is shifted along the y-axis.

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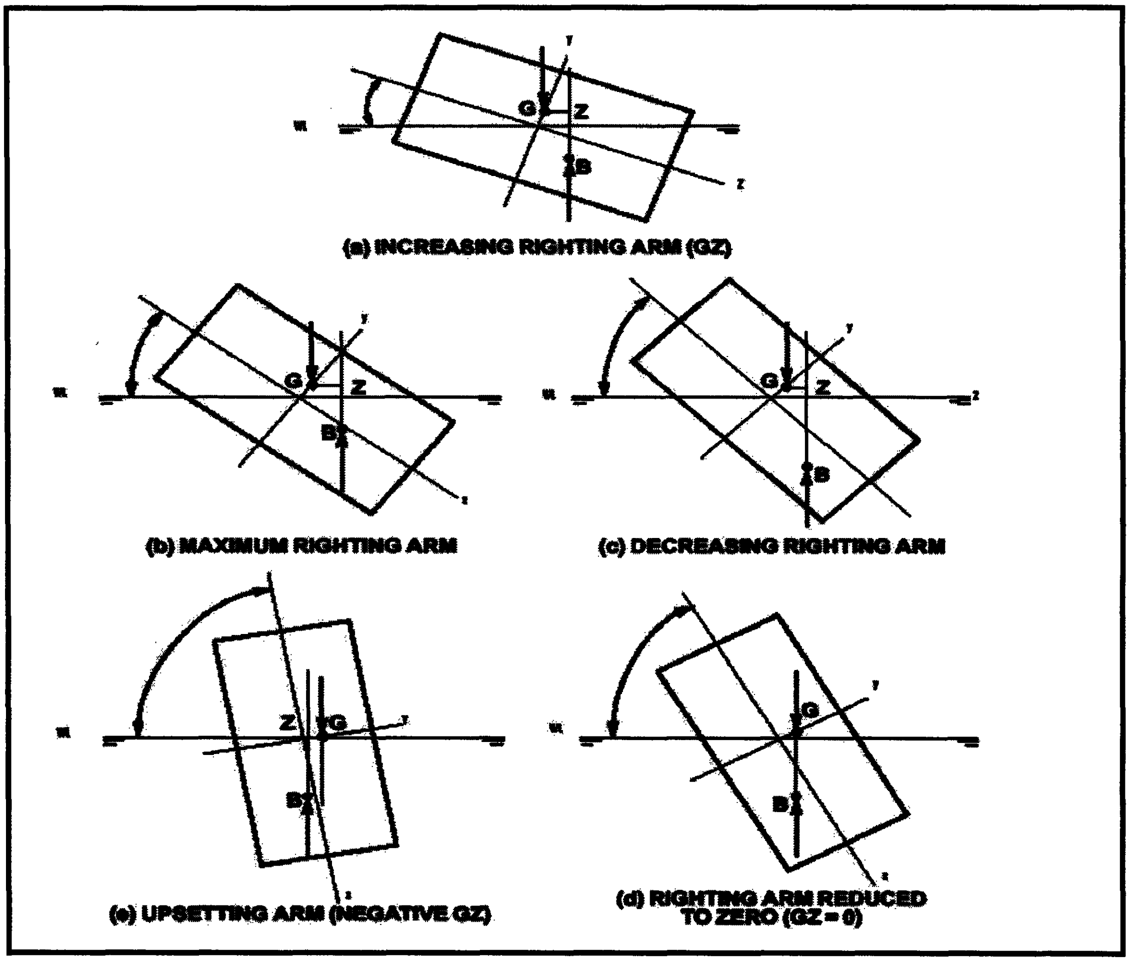
[2] http://web.nps.navy.mil/



(a) INCREASING RIGHTING ARM (GZ)

(b) MAXIMUM RIGHTING ARM

(c) DECREASING RIGHTING ARM

(e) UPSETTING ARM (NEGATIVE GZ)

(d) RIGHTING ARM REDUCED TO ZERO (GZ = 0)

Figure 2: Alternate conditions of the equilibrium of a floating body

2.4. Heeling arms

In addition to weight and buoyancy, there are other forces that may act on the ship. These forces are, generally, called upsetting forces and their magnitude determines the magnitude of the moment that must be produced by the weight-buoyancy couple in order to prevent capsizing or excessive heel.

External upsetting forces that can cause a ship-inclination may be:

- Wave action,
- Wind,
- Collision,
- Grounding,
- Shifting of onboard weights
- Addition or removal of weight
- High-Speed Turns
- Strain on mooring lines

- Towline pulls of tugs
- Entrapped water on deck

In the case where upsetting forces are acting on the ship, the ship heels to an angle whose value produces a moment by the forces of weight and buoyancy to equalize the moment developed by the upsetting forces. When the ship is exposed to a beam wind, the wind pressure acts on the portion of the ship above the waterline, and the resistance of the water to the ship's lateral motion is acting in an opposite direction in a point below the waterline, as can be seen in Figure 3[3]. As the ship heels from the vertical, the wind pressure, water pressure and their vertical separation remain approximately constant. The ship weight is unchanged and acts at a fixed point. Even though the magnitude of the buoyancy remains the same, the point through which it acts depends on the angle of heel. Subsequently, equilibrium will be reached when sufficient separation of the centers of gravity and buoyancy has been produced to cause balance between heeling and righting moments.

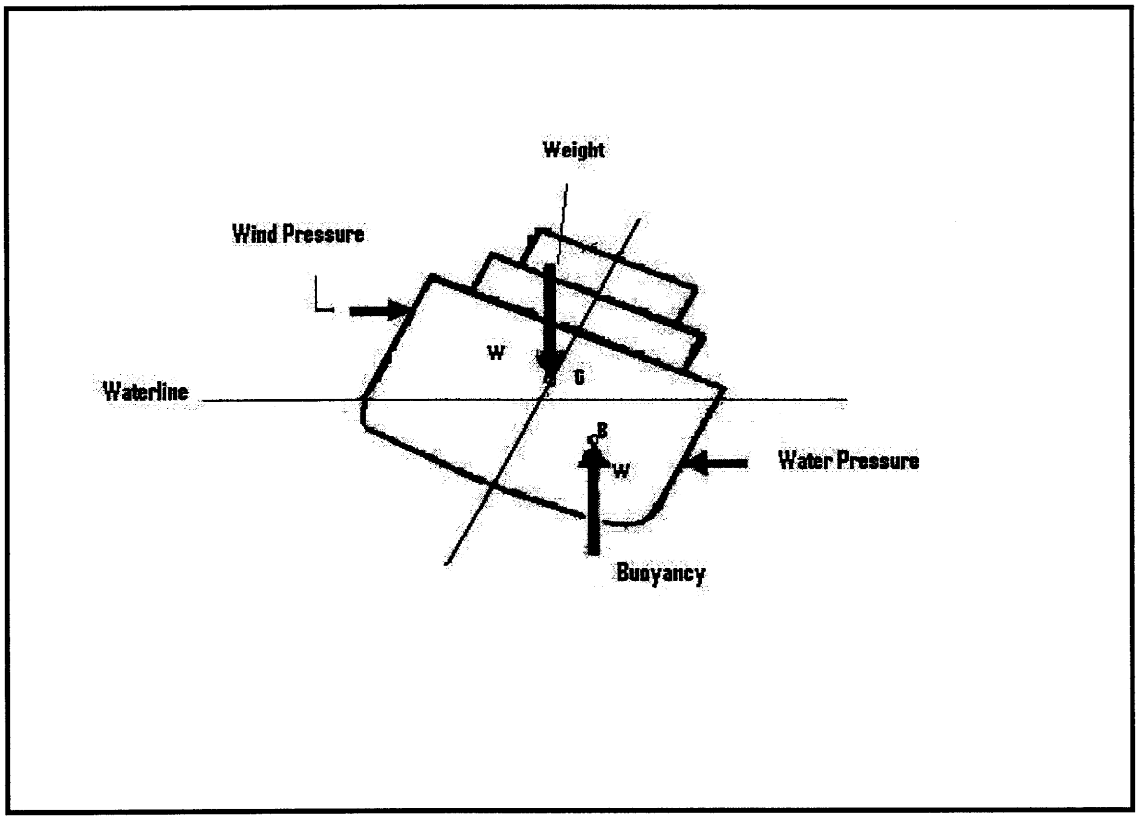


Figure 3: Effect of a beam wind

In any of the cases when upsetting forces are applied it is quite possible that under several circumstances, equilibrium would not be reached before the ship capsized. It is also possible that the equilibrium would not be reached until the angle of heel becomes so

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[3] Principles of Naval Architecture Volume I pp. 67

large that water would be shipped through topside openings, and the weight of this water would contribute to capsizing which otherwise would not have occurred.

2.5. Statical Stability Curves

2.5.1. Definition and Characteristic Points

The statical stability curves are a plot of the righting arms or the righting moments of the ship against the angle of heel for a given condition of loading. For any ship, the shape of this curve will vary with the displacement, the vertical and transverse position of center of gravity, the trim and the effect of free liquids' surfaces. The area under the curve physically represents the potential energy that the ship possesses at corresponding heel angles. The standard plotting form of the righting arm curve is shown in Figure 4[4]. In order to have a complete understanding of intact ship stability, it should be known not only how a righting arm curve is determined and used, but also why it is shaped as shown, and the significance of its typical features. The slope of the righting arm curve at zero is equal to the metacentric height of the ship. Up to about 5-10 degrees, the righting arm curve can be approximated by $GZ = GM_T \cdot \sin(\phi)$, where φ is the angle of heel.

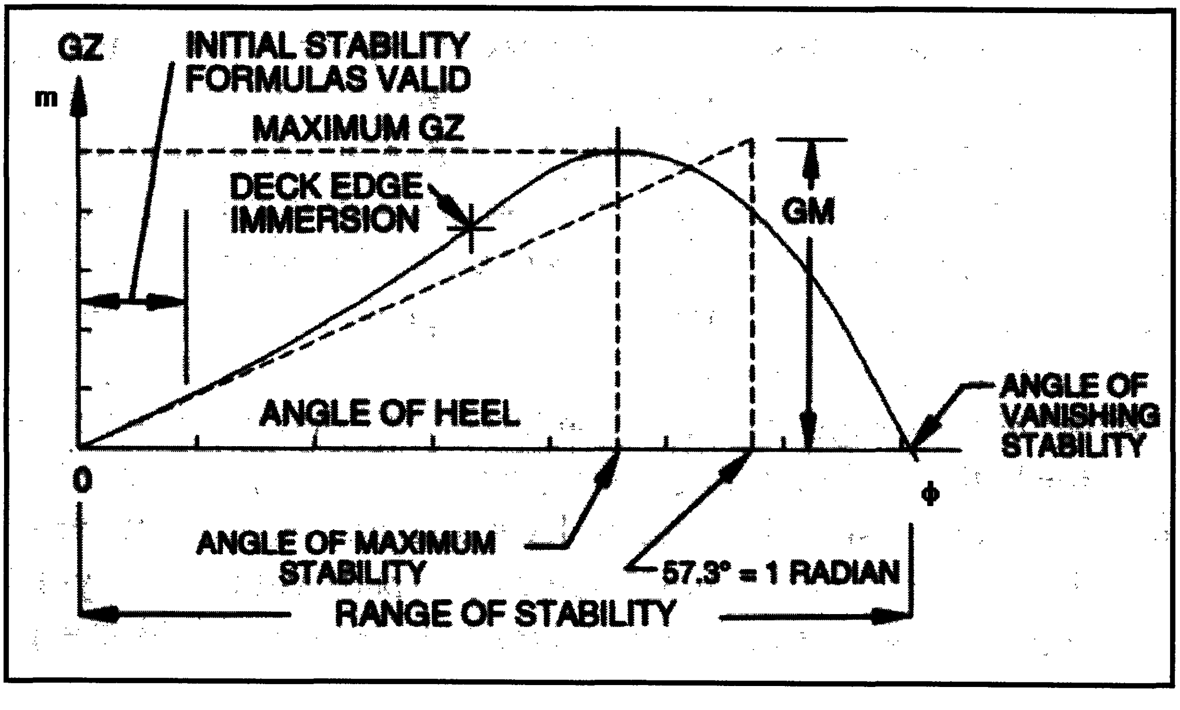

Figure 4: Characteristic points on a ship's curve of stability

The peak of the righting arm curve identifies two quantities that are important in evaluating the overall stability of a ship. These are the maximum righting arm and the angle of maximum stability. The importance of the maximum righting arm is that when multiplied by the ship's displacement it produces the maximum steady-state heeling moment that the ship can withstand without capsizing. Beyond the angle of maximum

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[4] http://web.nps.navy.mil/

stability, righting arms decrease, often more rapidly than they had increased up to that point. This rapid decrease, ultimately, leads to the point at which GZ becomes zero. The angle at which this occurs is the angle of vanishing stability. Any ship that inclines beyond this angle will capsize. In reality, capsize could occur at smaller angles due to the additive heeling impulses posed by dynamic conditions.

2.5.2. Dependency on the hull characteristics

The shape of the righting arm curve depends heavily on the ship's hull form, both under and above the design waterline. While initial stability (righting arms at small angles of heel) depends almost entirely on metacentric height, the overall shape of the stability curve is governed by hull form. Figure 5[5] shows how changing hull form increases or decreases righting arm by altering the position and movement of the center of buoyancy.

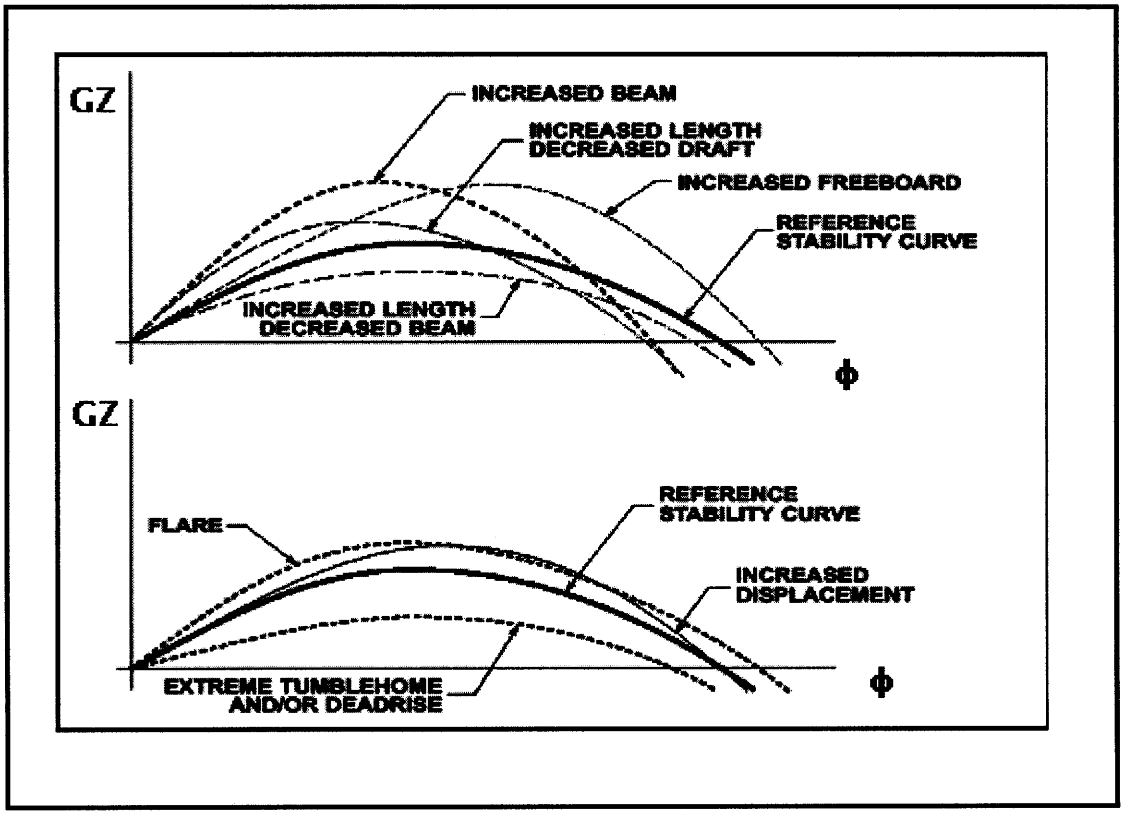

Figure 5: Dependence of the ship stability curve on the hull form and ship main dimensions

- **Beam.** Of all the hull dimensions that can be varied by the designer, beam has the greatest influence on transverse stability. Metacentric radius (BM) is proportional to the ratio B^2/T. BM, and therefore KM will increase if beam is increased while draft is held constant. If freeboard is held constant while beam is increased, the

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[5] http://web.nps.navy.mil/

angle of deck edge immersion is decreased; righting arms at larger angles and the range of stability are reduced.

- **Length.** If length is increased proportionally to displacement, with beam and draft held constant, KB and BM are unchanged. In practice, increasing length usually causes an increase in KG, reducing initial stability. If length is increased at the expense of beam, righting arms are reduced over the full range of stability. If length is increased at the expense of draft, righting arms will be increased at small angles, but decreased at large angles.

- **Freeboard.** Increasing freeboard increases the angle of deck edge immersion, increasing righting arms at larger angles and extending the range of stability. If draft is held constant, increasing freeboard causes a rise in the center of gravity, mitigating the benefits of increased freeboard to some extent.

- **Draft.** Reduced draft proportional to reduced displacement increases initial righting arms and the angle of deck edge immersion but decreases righting arms at large angles.

- **Displacement.** If length, beam, and draft are held constant, displacement can be increased only by making the ship fuller. The filling out of the waterline will usually compensate for the increased volume of displacement, and BM, as a function of $\frac{I_{xx}}{V}$, will increase. The height of the center of gravity will also be decreased by filling out the ship's form below the waterline. These changes will enhance stability at all angles.

- **Side and Bottom Profile.** Extreme deadrise (fining the bilges) or tumblehome in the vicinity of the inclined waterline reduces the increase in waterplane area and outward shift of the center of buoyancy, resulting in a shallow stability curve. Ships with flaring sides develop large righting arms because of the rapid increase in waterplane area and large shift of the center of buoyancy as the ship is inclined. A round-bottomed ship with vertical sides beginning somewhat above the water line, such as a tug or icebreaker, will roll easily to small angles of inclination but develop strong righting moments at large angles.

Chapter 3: Wind Effect on Hull

This Chapter is devoted to the study of the wind effect on the heeling of a ship. To do so, we make use of the theoretical background described in Chapter 2. A code that calculates the roll angle that a ship experiences due to the moments applied from the wind which strikes a ship, is proposed. Particular emphasis is placed on tumblehome hulls due to the special interest expressed by several navies around the world to acquire and operate this type of ship. Tumblehome ships have the advantage of reduced electromagnetic signatures because the angled ship structure above the water line reflects the electromagnetic waves in a direction that makes the trace of the ship more difficult. However, a tumblehome ship will have decreased righting arms GZ, in the whole spectrum of the heeling angles and the angle of vanishing stability will also be lowered.

3.1. Hull Selection

For the analysis and evaluation process three different hull forms were selected. A flare-sided, a wall-sided and a tumblehome. These types of hulls are schematically shown in Figure 6[6].

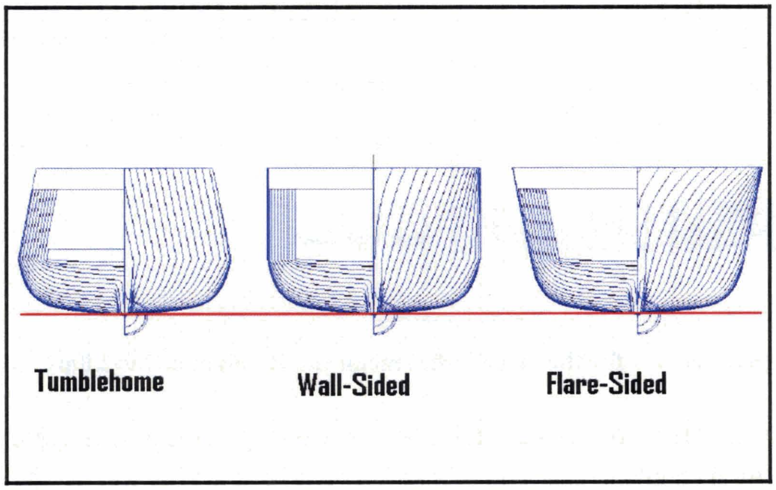

Figure 6: Schematics of the hull forms examined

These hulls were developed under the supervision of the Seakeeping Division of the NAVSEA Warfare Center Carderock Division and the name of the project is ONR. The RA curves for several values of initial metacentric height, GM_T, were constructed. GM_T limits for safe operations at sea, using Sarchin and Goldberg criteriaare shown below:

- Tumblehome: GM_T=2.01m

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[6] Seakeeping Division of NAVSEA Warfare Centers (Carderock Division)

- Wall-Sided: GM_T=1.10m
- Flare-Sided: GM_T=0.19m

For these values of GM_T the righting arm curves versus the angle of heel were constructed by NAVSEA, and they are indicative of the superiority of the flare-sided ships. These curves are shown in Figure 7[7]

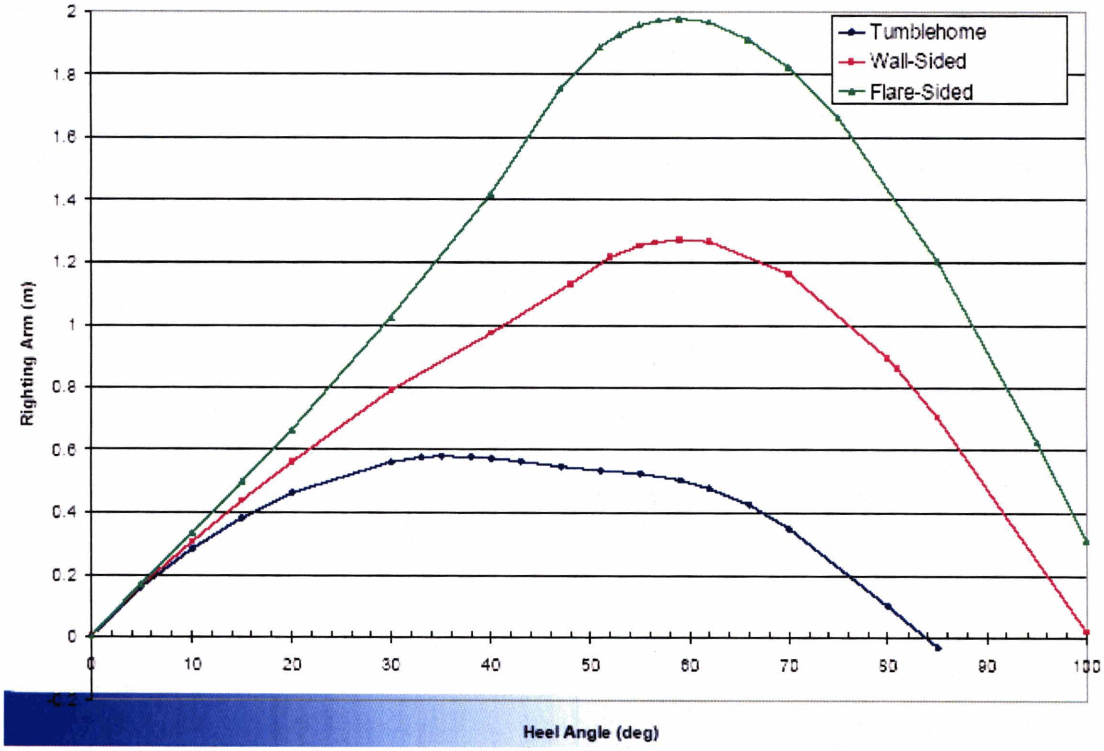

Figure 7: Righting arm curves for the large initial metacentric height (GM=2.0m)

While setting up the hulls to be examined, the following assumptions were made in order to make valid comparisons:

All of investigated hulls have the same principle characteristics L, B, T and the same displacement:

L=182.88m

B=24.11m

T=8.413m

Δ= 14264 ton

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[7] Seakeeping Division of NAVSEA Warfare Centers (Carderock Division)

- All of them have the same sail area. In other words, the heights of the ships' profiles above the waterline are assumed to be the same. This ensures that the forces applied by the wind and consequently the moments created are equal for all the types of the hull
- The local drag coefficient was chosen to be one. ($C_D=1$)
- The velocity profile was uniform throughout the superstructure.
- There are no other excitation forces applied to the hull of the ship apart from the wind force. Therefore, it is assumed that before any wind application the ship was in stillwater, and the initial angle of inclination and the initial angular velocity of the ship were zero
- The waterline did not rise on the high side when the ship rolled, therefore the wind roll force and moment would be proportional to the square of the cosine of the roll angle

Discussion on how these assumptions will be altered will follow in proceeding chapter.

3.2. Calculations Set up

The purpose of this work is to calculate and make finally a comparison of the following outcomes:

- Find the forces and the moments applied on the hulls by the wind
- Find the roll angle where the ship will balance after the application of the wind force for a long time. This will be called the static case
- Find the roll angle that the ship will experience as a result of a wind that gusts causing a heeling angle greater than that found in static case. This will be called the dynamic case.
- Finally, determine at which wind speed the ship will capsize, if any

The difference between the static and the dynamic case is the following. The static case evaluates the equilibrium roll angle for which the wind roll moment equals the ship righting moment. On the other hand, the dynamic case evaluates the extreme roll angle when the wind speed starts from zero and suddenly gusts to the prescribed wind speed which is maintained. In this case, the roll angle will overshoot the equilibrium value and as the ship behaves as a pendulum the energy provided by the wind will be absorbed by the ship restoring forces and finally the ship after a short period of time will be balanced to the angle calculated in static case.

This work will evaluate and plot the values of the angles described above for the following cases:

- The three different hull shapes mentioned above
- Two different righting arm curves for each hull with initial metacentric heights, $GM_T=1.5m$ and $GM_T=2.0m$
- Several wind speeds in increments of 2 knots for values ranging in the region of 50 knots to 100 knots

The wind direction with respect to astern winds is called the angle θ. For the purposes of this project, θ would take the following values: $30^0, 45^0, 60^0, 90^0$.It is obvious that the worst case scenario will be when the wind strikes the ship at an angle of 90^0.

Subsequently, the values of the roll angles in the static and dynamic cases will be plotted as a function of wind speed in each of the wind directions, for the several hull forms and the two initial metacentric heights.

3.3. Calculations

3.3.1. Projected Area Calculation

For calculation purposes, an existing preliminary design for the part of the ship above the waterline was used. This design is the DD(X) Multi-Mission Surface Combatant which is the future Surface Combatant for the US Navy.

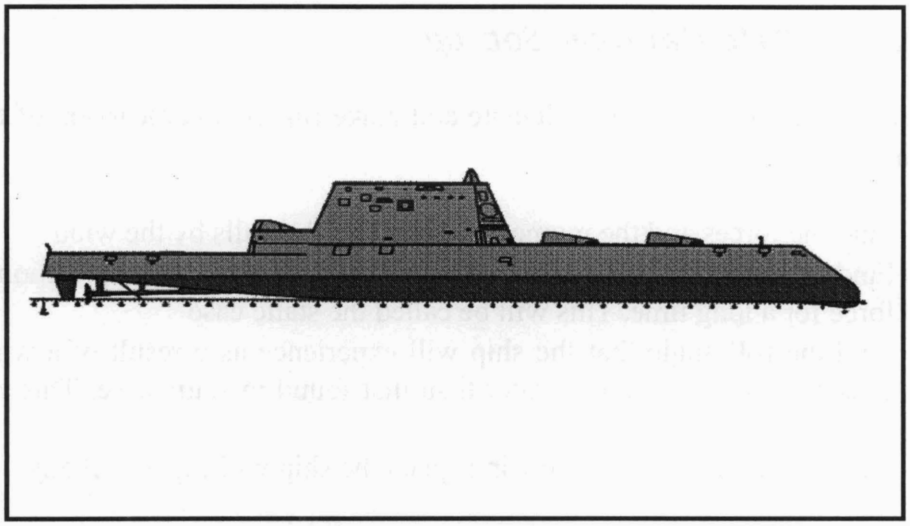

Figure 8: Figure of DD(x) for the calculation of projected to the wind area

"DD(X) will be about 600 feet long, 79 feet wide, draw approximately 28 feet, and be capable of speeds in excess of 30 knots. Displacement will be approximately 14,000 tons. The ship's tumblehome design will make it appear smaller than it actually is on radar. Although nearly twice the displacement of a Spruance-class destroyer, through signature reductions and its unique tumblehome hull design, DD(X) will be a stealthy warship and present a radar cross section a fraction of Spruance-class ships."

Source: http://www.globalsecurity.org/military/systems/ship/dd-x-design.htm

Because the ship is not yet constructed, and because the design plans are confidential the ship scheme given in Figure 8[8] was used. Knowing that the ship has an overall length of

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[8] From the site of www.globalsecurity.com

about 600ft or 182.88m and measuring ship length from the figure, a ratio of the real ship and ship of the figure, called λ was created. Using that ratio, and measuring the heights of the ship's profile in figure, the real ship profile heights can be estimated.

The profile of the projected area normal to the wind was represented by two single-column tables: one denotes the longitudinal position along waterline and another the corresponding heights. The table of longitudinal positions is in meters starting from x=0m at the stern of the ship and ending at x=182.88m at the bow. Because of the particular ship profile, the positions of measurements are not evenly spaced. Instead, the positions of measurements are selected according to hull profile changes. Both tables have 22 elements: 22 longitudinal positions, denoted as L_j and 22 corresponding heights, denoted as H_j. These tables can be found in Appendix III.

In a second step, we assume that j is taking values from 0 to 21, in order to cover all the longitudinal positions and heights. A function f(j) is defined to calculate the projected wind area of a small trapezoid between the positions L_j and L_{j+1} with corresponding heights H_j and H_{j+1}.

$$f_j = \frac{1}{2}(H_j + H_{j+1}) \cdot (L_{j+1} - L_j) \tag{1}$$

The whole projected area of the ship will then be given by the summation of all small trapezoids:

$$\text{Area} = \sum_{j=0}^{20} f_j \tag{2}$$

3.3.2. Calculation of the force and the moment applied by the wind

Another function of j, a(j)[9] is set to calculate the moment of area of each trapezoid about the waterline, and the sum of those will represent the first moment of the total projected wind area about the waterline, which is called M_x:

$$a(j) = \frac{1}{2} \cdot (H_j + H_{j+1}) \cdot (L_{j+1} - L_j) \cdot \frac{(H_j)^2 + (H_j \cdot H_{j+1}) + (H_{j+1})^2}{3 \cdot (H_j + H_{j+1})} \tag{3}$$

$$M_x = \sum_{j=0}^{20} a(j) \tag{4}$$

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[9] http://www.efunda.com/math/areas/IndexArea.cfm

M_x divided by the Area will give the centroid of the area, Centroid_y, with respect to the waterline

$$\text{Centroid}_y = \frac{M_x}{\text{Area}} \qquad (5)$$

The force on a surface can then be derived using:

$$F = \frac{1}{2} \cdot \rho_{air} \cdot C_D \cdot (V_a \cdot \sin\theta)^2 \cdot \sum_{i=0}^{20} f(j) \qquad (6)$$

where

C_D is the local drag coefficient (C_D=1.0),

ρ_{air} is the air density (ρ_{air}=1.2kg/m^3),

V_a is the wind velocity in m/sec., and

θ is the angle between the wind direction and the ship direction (0° - wind is coming from the stern and 180° - wind is coming from the bow) as it is shown in Figure 9.

The longitudinal fore-and-aft component of the wind has also some effect, due to the curvature of superstructure. The projected area to this component is very small compared to the projected area of the lateral component, thus the moment created from the horizontal velocity is negligible and can therefore be ignored. All following calculations do not take this horizontal component of the wind into account.

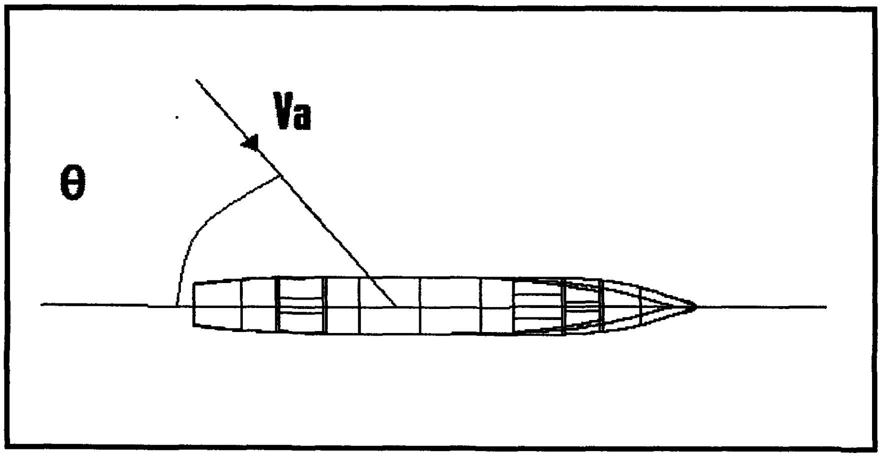

Figure 9: Angle of attack of the wind with respect to the ship

Another function of j, termed d(j), is set up to calculate the moment applied by the wind on each of the small trapezoids that constitute the hull. This moment will be equal to the product of the force applied on each piece and the lateral distance, l, of the centroid of each piece from the point where the force from the water resistance is applied. It can be assumed that this point is at half draft, T/2. This issue is clarified in Figure 10[10].

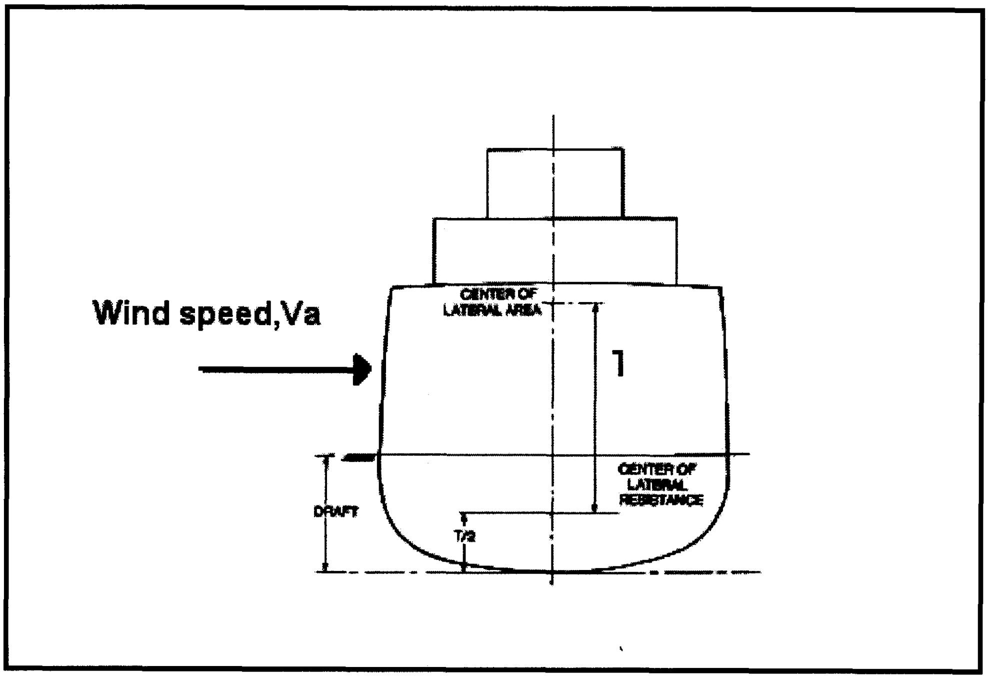

Figure 10: Moment applied by the wind on a hull

This formula is derived as follows:

$$d_j = \frac{1}{2} \cdot f_j \cdot \left(\frac{H_j}{2} + \frac{H_{j+1}}{2} + \mathrm{Draft}\right) \tag{7}$$

where the total moment applied to the hull by the wind is the sum of all the moments applied to each trapezoid:

$$M = \frac{1}{2} \cdot \rho_{air} \cdot C_D \cdot (V_a \cdot \sin\theta)^2 \cdot \sum_{i=0}^{20} d(j) \tag{8}$$

The force and the moment found using the above equations is what the ship experiences in the upright position. As the ship inclines to some angle, φ, the force and the moment applied on the hull is actually multiplied by a factor ($\cos^2\varphi$) because in that case the wind

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[10] Principles of Naval Architecture Volume I pp. 67

hits the ship in an angle φ so the ship realizes the $Va \cdot \cos\phi$ component. Furthermore, in the expression giving the force and the moment applied by the wind (equations 6 &. 8), speed term is squared; consequently, the factor cos(φ) is also squared.

3.3.3. Ship Righting Moment Calculation

Righting arm data for various heel angles was collected for each of the three hulls examined. This data ,collected from the ONR project, gives values of righting arms versus heel angle, GZ(φ), at initial metacentric heights of GM=1.5m and GM=2.0m for tumblehome, wall sided and flare sided designs.

Since the ship used for the ONR project is similar to DD(x) but smaller (152.5m compared to 182.88), all the righting arms from the curves constructed for ONR are multiplied by a factor 1.2, which is the ratio of the DD(x) length over the ONR project ship's length. The decision to multiply with the ratio of the lengths and not the ratio of the displacements is made because the righting arms are measured in meters. Therefore it was proper to multiply with a ratio of a length scale, which is of the same dimension. A cubic spline was fitted to those points, in order to get a continuous function of GZ(φ) for that discrete characterization, as shown in Appendix I. This spline representation will help the MathCAD to use the function GZ(φ) in the equations that will give the static and dynamic solution for the roll angle experienced by the ship under wind effect.

3.3.3.1. Evaluation of roll angle in static case

For the static roll angle solution, a function Γ(φ) is created. This function represents the difference between the moment applied by the wind, $\left[M \cdot \cos^2\phi\right]$ and the restoring moment of the ship, $\Delta \cdot GZ(\phi)$

$$\Gamma(\phi) = M \cdot \cos^2\phi - \Delta \cdot GZ(\phi) \tag{9}$$

The root of that function is the angle φ that will make both terms equal. This root will be the equilibrium angle that the ship will balance when is hit by a constant velocity wind.

3.3.3.2. Evaluation of roll angle in dynamic case

In an attempt to describe the complicated dynamic phenomena associated with ship heeling, we represent the dynamic stability U_φ of a ship as the difference between the potential energies of the ship heeled at an angle φ and upright at *0* degrees. Since the work required to heel the ship by a differential $d\varphi$ is

$$\text{Energy} = \Delta \cdot GZ(\phi) \cdot d\phi \tag{10}$$

The total work required heeling the ship up to an angle φ, or in other words, the dynamic stability U_φ is expressed by:

$$U_\phi = \int_0^\phi \Delta \cdot GZ d\phi = \Delta \cdot \int_0^\phi GZ d\phi \qquad \textbf{(11)}$$

The dynamic stability is therefore directly proportional to the integral under the righting arm curve. When the external moment by the wind which is a function of $\varphi, M \cdot \cos^2 \phi$, is applied, the ship's equation of motion, taking into account that water is acting as a damper to the rolling of the ship, becomes:

$$(\Delta_{44} + A_{44}) \cdot \frac{d^2}{dx^2}\phi + B_{44} \cdot \frac{d}{dx}\phi + C_{44} \cdot GZ(\phi) = M \cdot \cos^2 \phi \qquad \textbf{(12)}$$

with initial conditions:

$$\phi(0) = 0 \qquad \phi'(0) = 0$$

where:

- Δ_{44} represents the moment of inertia of the ship around the roll axis and equals the squared radius of gyration, k_x^2, multiplied by the ship displacement converted in kg to match the units
- A_{44} represents the added mass moment of inertia of the hull around the roll axis
- B_{44} is the roll damping coefficient
- C_{44} is the restoring force coefficient and has the value of the displacement, converted in mass units, multiplied by the gravity acceleration g , (C_{44}=Δ g)

Because the offsets of the hulls studied for the purposes of this research are not known, the only known value in equation (12) is C_{44}. The values Δ_{44}, A_{44}, B_{44} will be calculated making some assumptions. The value that can be calculated most readily is Δ_{44} making the assumption that the radius of gyration is one third of the beam of the ship.

For A_{44} and B_{44} the following procedure will be followed:

Step 1: It is known that if the sectional added mass, α_{44} and b_{44} is given for each section of the ship at any position-x then integration of this along the length of the ship will give, consequently, the values of A_{44} and B_{44}. The sectional added mass terms, α_{44} and b_{44}, can be found by solving the 2-D hydrodynamic problem shown in Figure 11[11].

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[11] Principles of Naval Architecture Volume III Figure 46 at page 62

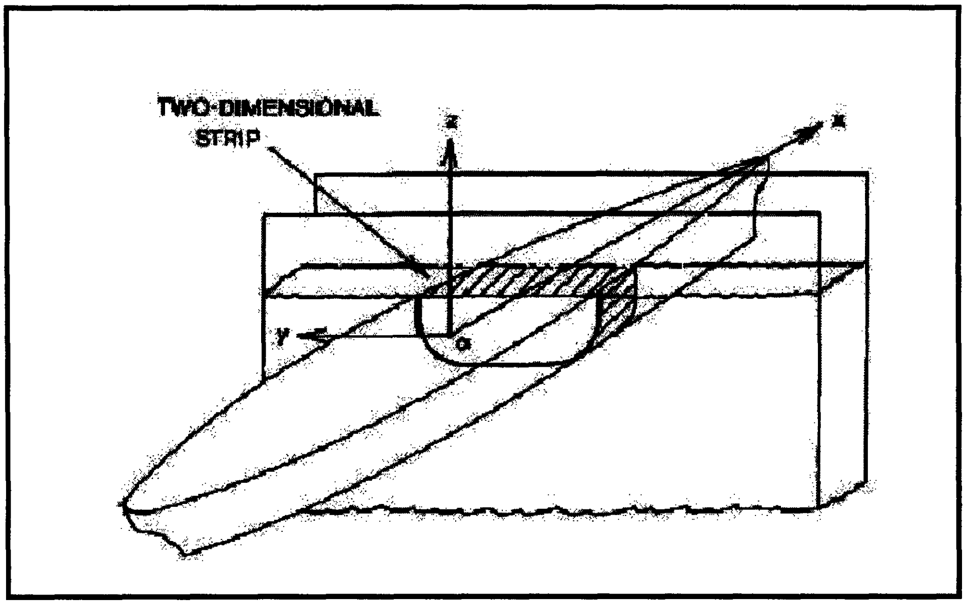

Figure 11: Two dimensional strip theory for the calculation of α_{44}, b_{44}

Then, using strip theory the values of the added mass terms for the whole ship, A_{44} and B_{44}, can be determined by using the following equations:

$$\begin{aligned} A_{44} &= \int_L \alpha_{44}(x)dx \\ B_{44} &= \int_L b_{44}(x)dx \end{aligned} \qquad (13)$$

Step 2: As the exact offsets of the ship are not known, the exact calculation of sectional coefficients, α_{44} and b_{44} is impossible. The use of experimental results is necessary. Using Figure 46 on p.62 of PNA (Principles of Naval Architecture Volume III) we can obtain a non dimensional sectional added mass moment of inertia and damping coefficient in roll for a rectangle of beam B and cross-sectional area A, as a function of non-dimensional frequency of the motion. A mean value from these charts is chosen as:

$$\begin{aligned} &\frac{\alpha_{44}}{\rho_{sw} \cdot A \cdot B^2} = 0.05 \\ &\frac{b_{44}}{\rho_{sw} \cdot A \cdot B^2} \cdot \sqrt{\frac{B}{2g}} = 0.04 \end{aligned} \qquad (14)$$

The purpose of this thesis is not to derive the exact values of the added mass terms but to predict the roll angles experienced by the ship under high speed winds in the dynamic case. Because the added mass moment of inertia is very small compared to the moment of inertia of the ship and because doubling the damping coefficient will change the maximum roll angle by less than four percent, we can assume the validity of the above values from the chart given in PNA. In the following step, a method of finding the added moment of inertia and the damping coefficients of a slender body when sectional coefficients are known in any position of the ship will be presented, for future reference.

Step 3: Using Figure 12[12] that shows the waterplane area of the DD(x) at draught waterline, a function of the half-beam of the ship can be obtained.

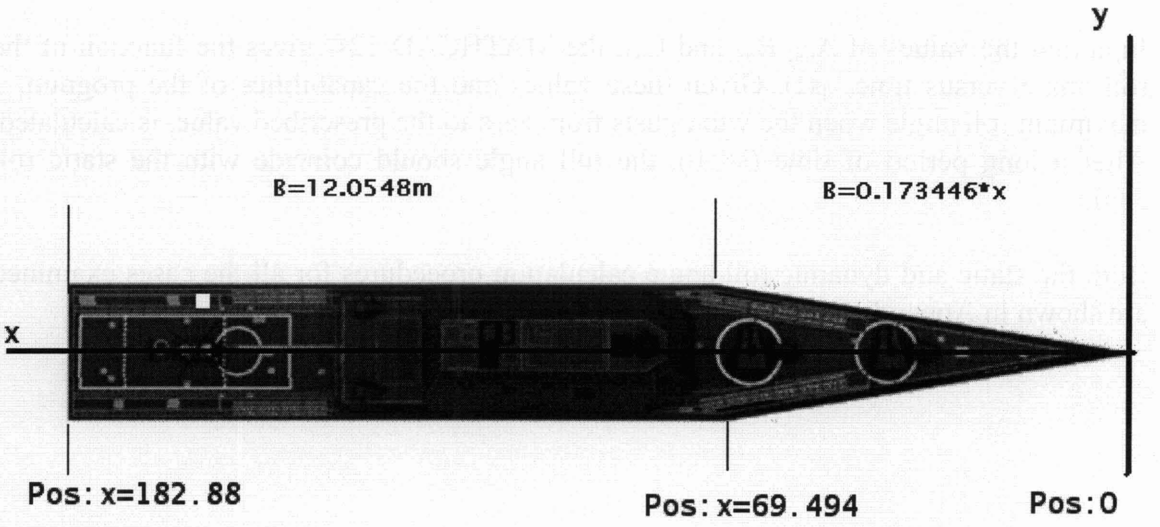

Figure 12: Beam of the waterplane area as a function of ship length

So the function of the half-beam of the ship with respect to the longitudinal position (bow defined as x=0) is given from the following formulas:

$$B = 0.173446 \cdot x \qquad \text{for} \qquad 0 \le x \le 69.494\text{m}$$

$$B = 12.0548 \qquad \text{for} \qquad 69.494\text{m} \le x \le 182.88\text{m} \qquad \textbf{(15)}$$

Assuming that draft remains unchanged for the entire length, the cross-sections of the ship will be rectangles of different beams and same drafts with an area $A = B \cdot T$. Therefore combining the equations **(13)**, **(14), (15)**, A_{44} and B_{44} can be written down as:

$$A_{44} = 2 \cdot \int_0^L 0.05 \cdot \rho_{sw} \cdot T \cdot B^3 dx$$

$$B_{44} = 2 \cdot \int_0^L 0.04 \cdot \rho_{sw} \cdot T \cdot \sqrt{2g} \cdot B^{\frac{5}{2}} dx \qquad \textbf{(16)}$$

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[12] www.globalsecurity.com

The solution of the above integrals in order to obtain a value for the A_{44} and B_{44} terms is shown in Appendix II. A factor of two at the integrals exists for calculate A_{44} and B_{44} for the whole ship as the function B is giving the half beam.

This step is created to generate a reasonable procedure of getting these coefficients and it can be used as a reference in future utilization, when the sectional added mass terms and the offsets of the ship are known exactly.

Inputting the values of $A_{44,}$ B_{44} and C_{44}, the MATHCAD 12© gives the function of the roll angle versus time, $\varphi(t)$. Given these values and the capabilities of the program, a maximum roll angle when the wind gusts from zero to the prescribed value, is calculated. After a long period of time ($t>>0$), the roll angle should coincide with the static roll angle.

Both the static and dynamic roll angle calculation procedures for all the cases examined are shown in Appendix III.

Chapter 4: Simulation Results

4.1. Results with zero initial conditions

This chapter presents the simulation results as predicted by the model proposed in Chapter 3. The need to obtain roll angles for a) static and dynamic cases, b) three different hull types, c) two different initial metacentric heights, d) four different wind angle of attack, and e) twenty six wind speeds in the range of 50 to 100 knots in steps of two knots, produces a large number of required simulations (1248 combinations) that would be very tedious to run manually in the MATHCAD 12© code.

In order to accommodate this large number of runs, a MATLAB© code is developed that uses the equations described in Chapter 3 to statistically and graphically obtain the roll angle values for all described cases. This code is included in Appendix IV. The validity of the MATLAB© code was verified by cross checking the results that each program gives for certain cases.

Tables of the roll angles of ship heeling for both static and dynamic cases for each hull form and each initial metacentric height for all the combinations of wind speeds and directions are presented in Appendix V.

In what follows, the results for static and dynamic cases are presented in graphic format. The x-axis and y-axis in the graphs represent the wind speed in knots and the roll angle in degrees, respectively.

At the end of this section a table and a graph for the worst-case scenario (this happens at beam winds [$\theta=90^0$]) are also constructed which will help to make the comparison.

4.1.1. Tumblehome Hull Form

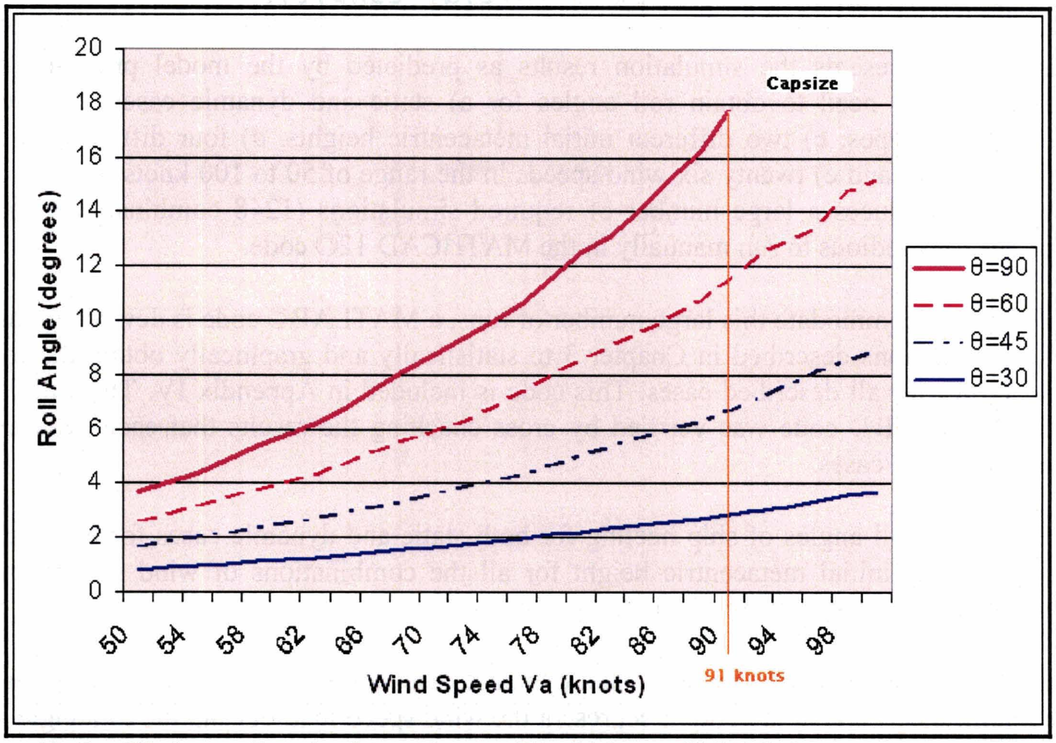

Figure 13: Equilibrium roll angles for static case (Tumblehome GM=1.5m)

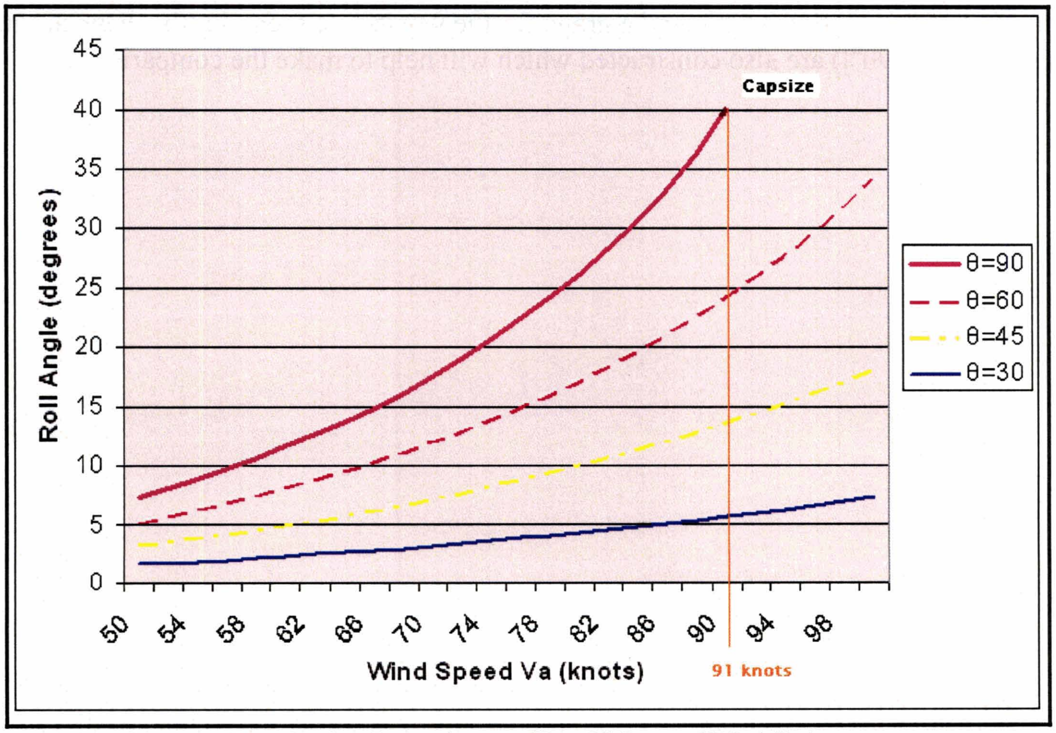

Figure 14: Maximum roll angles for dynamic case (Tumblehome GM=1.5m)

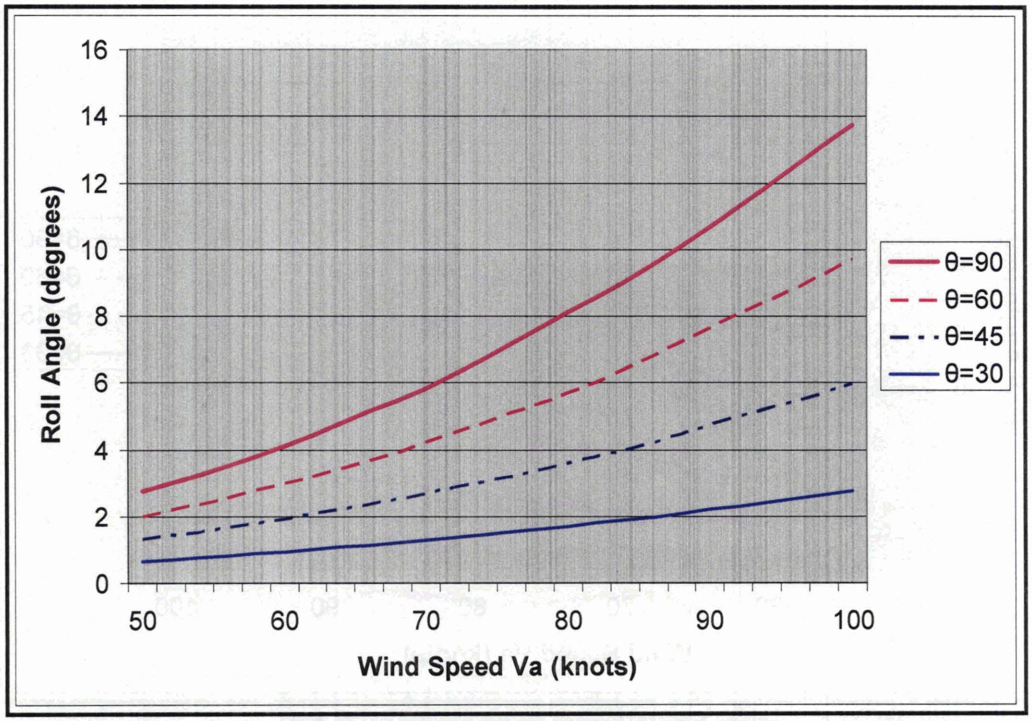

Figure 15: Equilibrium roll angles for static case (Tumblehome GM=2.0m)

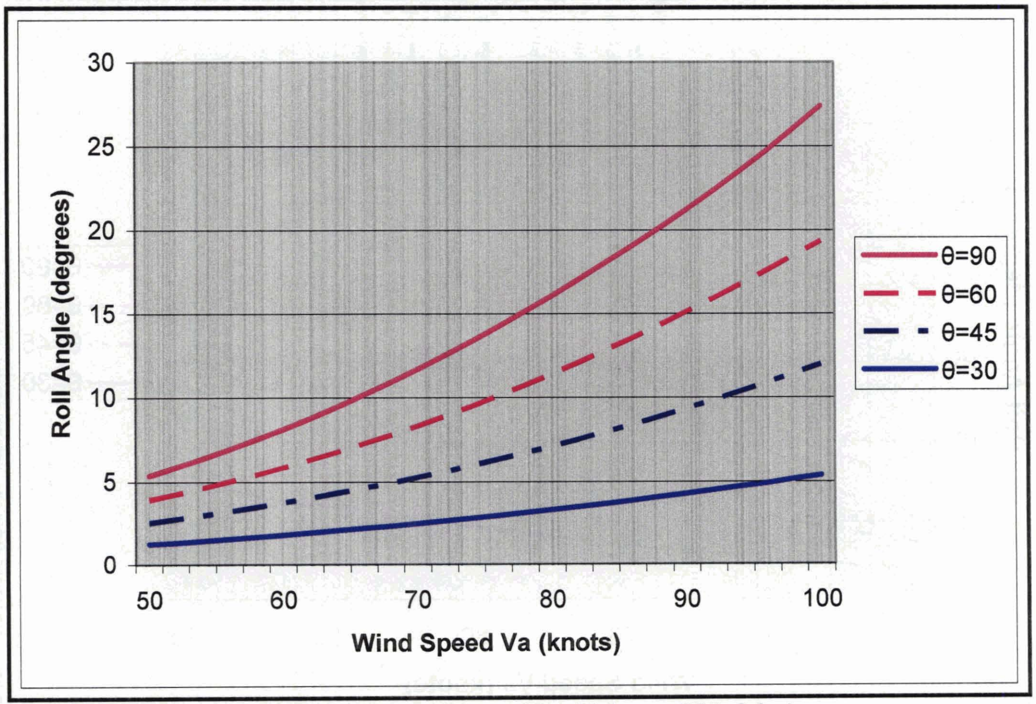

Figure 16: Maximum roll angles for dynamic case (Tumblehome GM=2.0m)

4.1.2. Wall Sided Hull Form

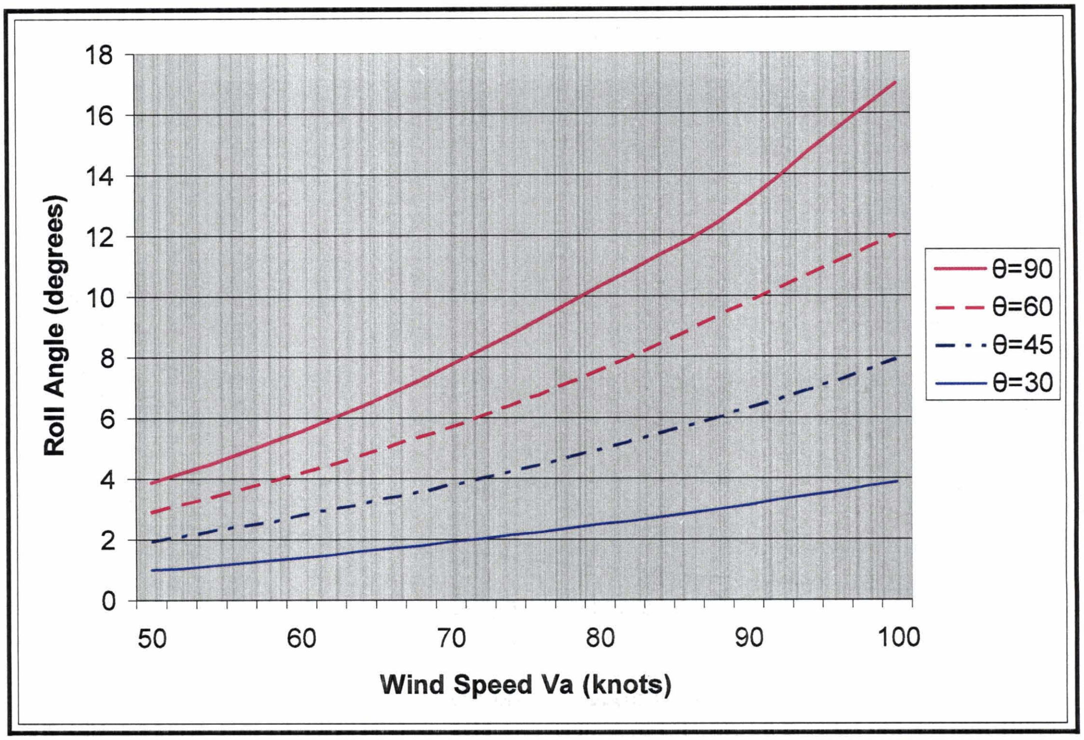

Figure 17: Equilibrium roll angles for static case (Wall Sided GM=1.5m)

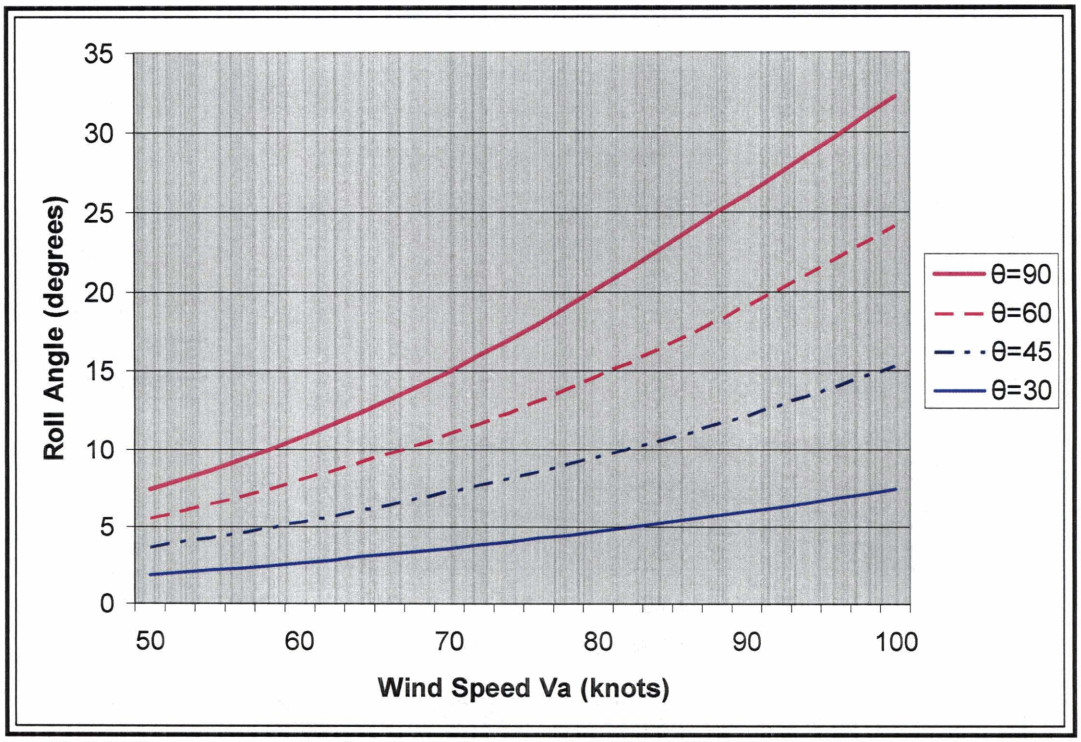

Figure 18: Maximum roll angles for dynamic case (Wall Sided GM=1.5m)

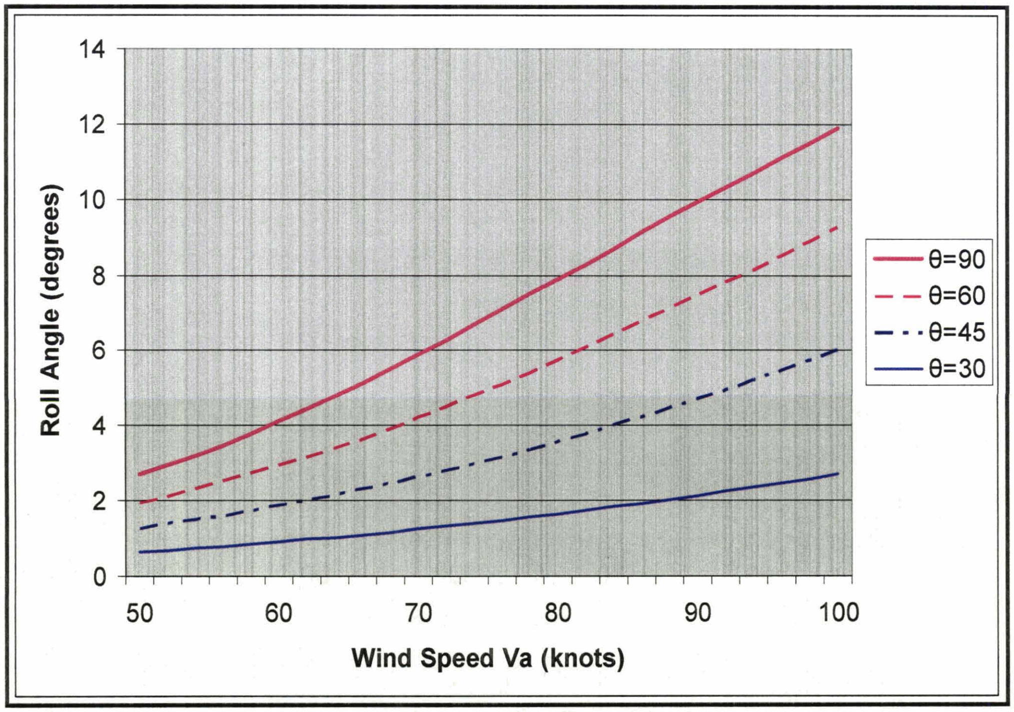

Figure 19: Equilibrium roll angles for static case (Wall Sided GM=2.0m)

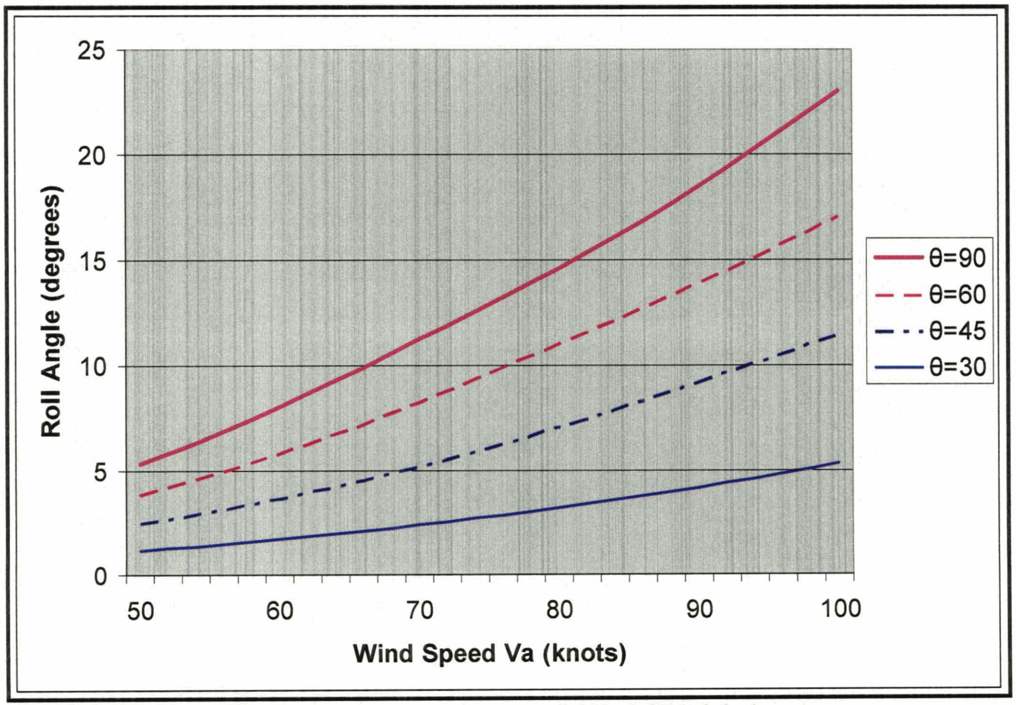

Figure 20: Maximum roll angles for dynamic case (Wall Sided GM=2.0m)

4.1.3. Flare-Sided Hull Form

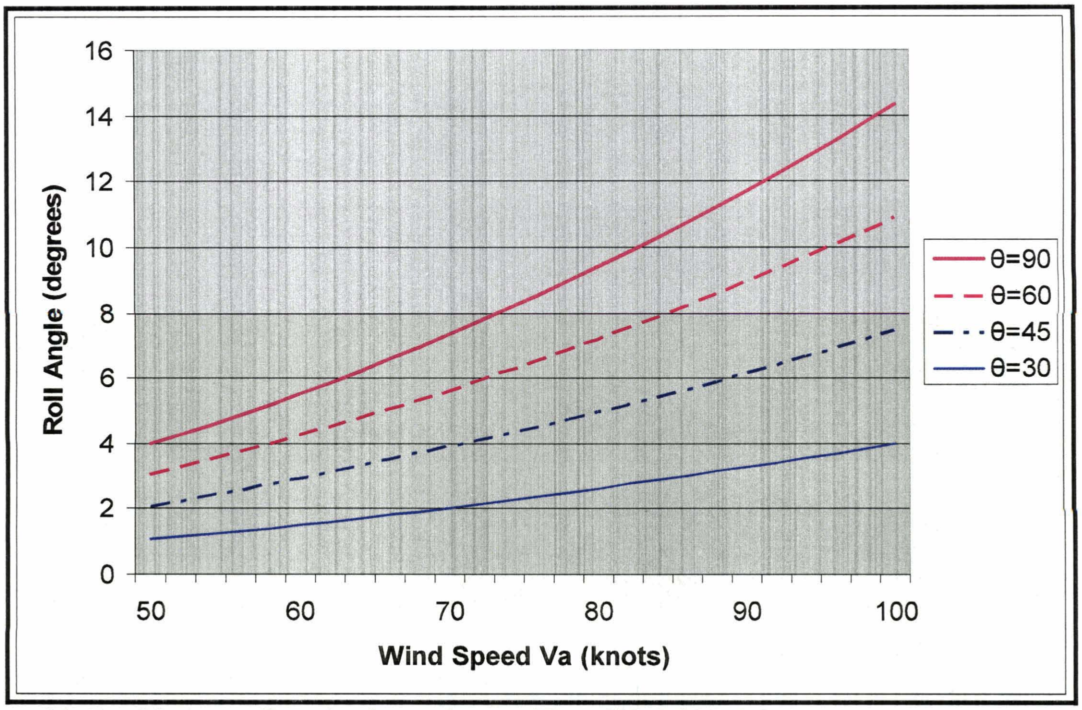

Figure 21: Equilibrium roll angles for static case (Flare Sided GM=1.5m)

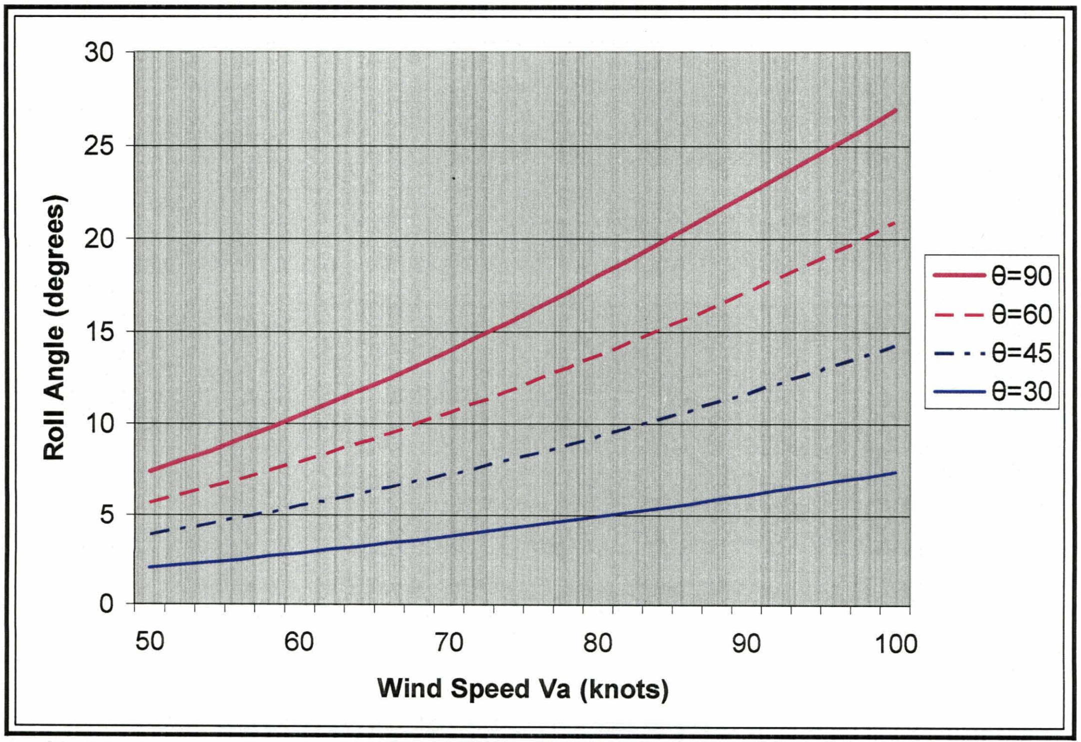

Figure 22: Maximum roll angles for dynamic case (Flare Sided GM=1.5m)

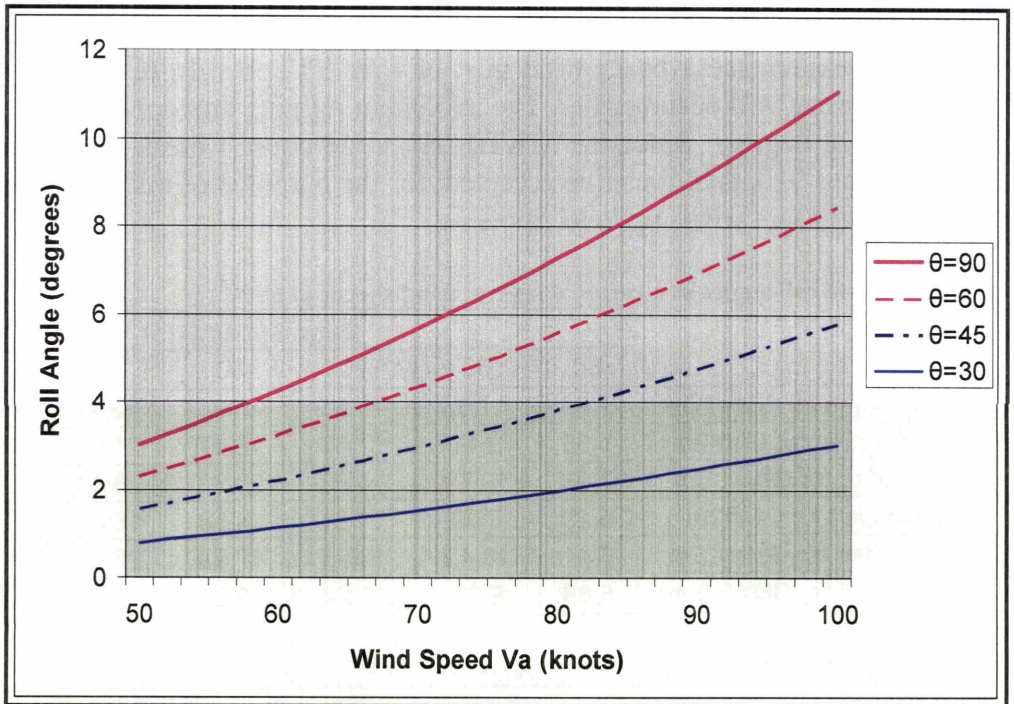

Figure 23: Equilibrium roll angles for static case (Flare Sided GM=2.0m)

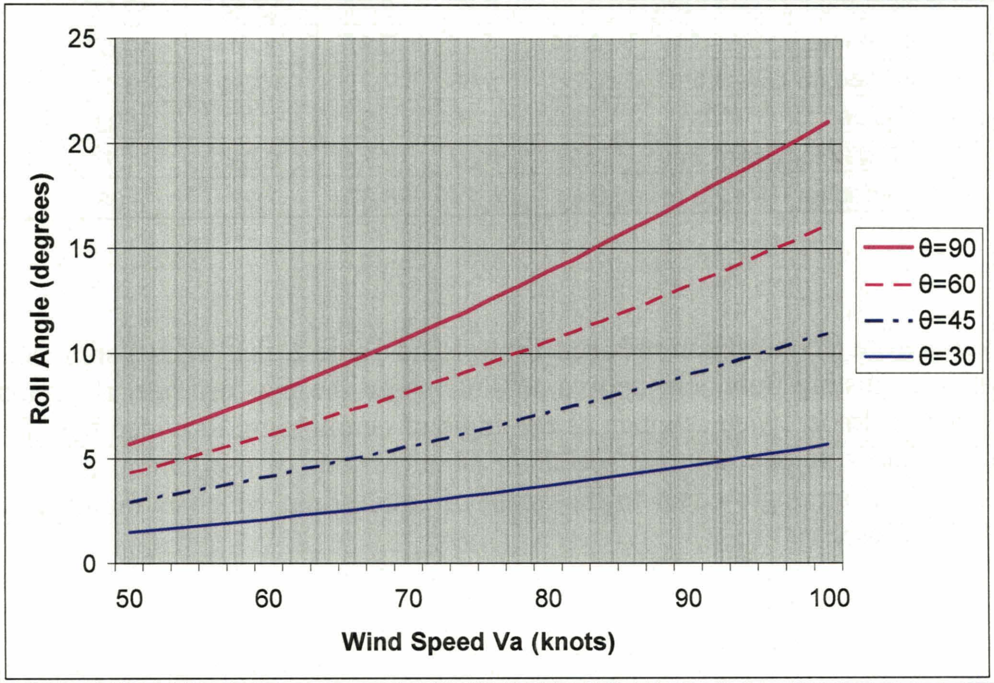

Figure 24: Maximum roll angles for dynamic case (Flare Sided GM=2.0m)

4.1.4. Discussion of the results

As can be seen from Figure 13 through Figure 24 as well as from the data presented in Table 1 and Table 2, the tumblehome ship of initial metacentric height of 1.5m will capsize if it will experience a beam wind gust of over 90 knots. In reality, there is a possibility that capsize will occur earlier. The maximum righting arm appears at an angle of inclination of 28 degrees. Since the MATLAB© code doesn't break down until the wind speed becomes 91 knots, it can be accepted, for the purposes of this thesis, that the ship will withstand beam winds up to 91 knots.

Table 1: Dynamic case roll angles as a result of several wind speeds at $\theta=90^0$

		Wind Speed (kts)					
		50	60	70	80	90	100
Hull Form	Tumblehome for GM=1.5m	7.34	11.63	17.51	26.21	40.17	Capsize
	Tumblehome for GM=2m	5.35	8.11	11.68	16.07	21.19	27.39
	Wall Sided for GM=1.5m	7.39	10.79	14.99	20.22	26.14	32.25
	Wall Sided for GM=2m	5.29	8.02	11.21	14.58	18.44	23.05
	Flare Sided for GM=1.5m	7.41	10.42	13.95	17.99	22.37	26.85
	Flare Sided for GM=2.0 m	5.68	8.02	10.74	13.87	17.34	21.02

Table 2: Static case roll angles as a result of several wind speeds at $\theta=90^0$

		Wind Speed (kts)					
		50	60	70	80	90	100
Hull Form	Tumblehome for GM=1.5m	3.72	5.80	8.77	12.54	17.85	Capsize
	Tumblehome for GM=2m	2.74	4.10	5.82	8.11	10.67	13.75
	Wall Sided for GM=1.5m	3.86	5.58	7.72	10.31	13.10	17.00
	Wall Sided for GM=2m	2.69	4.10	5.87	7.87	9.93	11.88
	Flare Sided for GM=1.5m	3.97	5.52	7.34	9.39	11.71	14.33
	Flare Sided for GM=2.0 m	3.01	4.24	5.67	7.28	9.08	11.08

It is obvious from a comparison between Table 1 and Table 2, that when a ship receives a wind which is gusting from zero up to a nominal speed the ship will heel at a maximum angle which is almost twice as much as the angle of equilibrium. Provided that the wind continues to blow at this nominal speed for some periods of oscillation, the ship will remain heeled at an angle equal to the angle of equilibrium which is found under the study of static case.

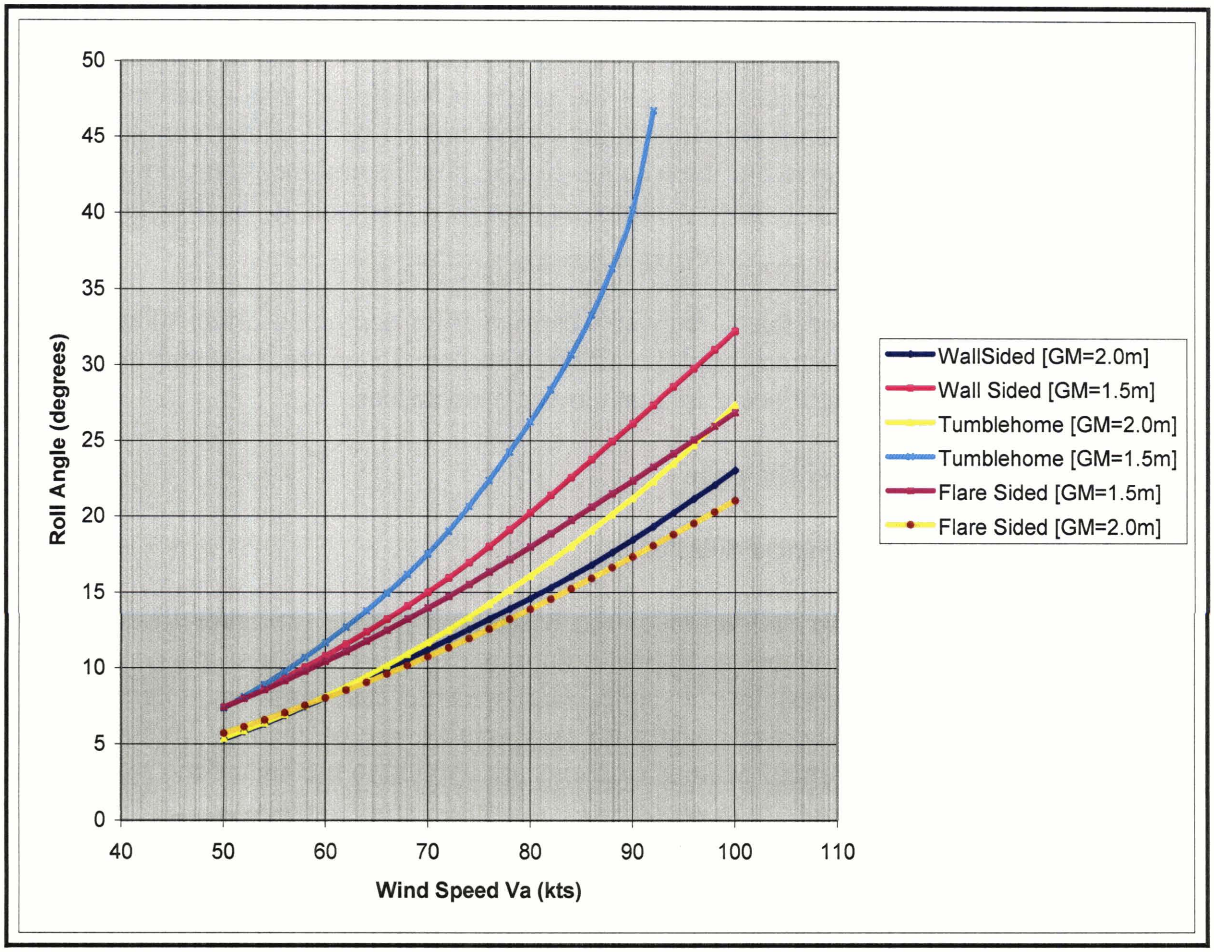

Figure 25: Dynamic case maximum roll angles for all hull forms and GMs at $\theta=90^0$

Figure 25 presents the maximum roll angles obtained for the dynamic case for the range of speeds from 50 knots to 100 knots for all the different hulls examined. It can be observed that in the case of initial metacentric height of GM= 2.0m, the difference between the three different hull forms is less than the difference observed for the GM= 1.5m case. For both cases, however, roll angles in the vicinity of wind speeds of 50 knots are essentially the same but they tend to deviate as the wind speed is increased. It should be noted that in the case of the initial metacentric height of 1.5m the deviation is much bigger than the deviation occurs with initial metacentric height of 2.0m.

In any case, as it can be understood by graphs and table, the flare sided ship is superior in terms of stability. Wall sided ships are less stable, while the tumblehome ships show the least desirable stability under high winds' effect.

As claimed by NAVSEA experiments on tumblehome hulls, the adequate metacentric height for a ship of this kind to be stable is 2.0m and more. This is also confirmed by the presented calculations.

The graphs presented in paragraphs 4.1.1-4.1.3 demonstrate that the roll angles decrease as a ship veers in a way to reduce the wind angle of attack to less than 90^0. The reduction of the angles of roll becomes greater as the angle between the wind and the ship is reduced. Consequently, a ship which is going to experience bad weather conditions has two options: one is to try to avoid the weather if time permits and the other, if there is no time to avoid the weather, is to keep a course as parallel as possible to the direction of the blowing wind.

Also, it must be mentioned that a ship will capsize from combined effect of wind and waves. In the above calculations only the effect of the wind is given. In reality with both wind and waves, capsize will occur in much lower wind speeds.

4.1.5. Validation of the code

4.1.5.1. Analytical Solution

This section is devoted to validation of the MathCAD© code. In order to do so we investigate a special case where analytical solutions exist and compare the results with the numerical solution given by the code. The dynamic case problem, expressed by equation (12), can be solved analytically for very small angle of heeling. This relates to the physical scenario that small heeling moments are applied to the hull of the ship by the wind.

In that case equation (12) can be written in the form:

$$(\Delta_{44} + A_{44})\cdot\frac{d^2}{dx^2}\phi + B_{44}\cdot\frac{d}{dx}\phi + C_{44}\cdot GM\cdot\phi = M_{10} \qquad \textbf{(17),}$$

where we use the approximation for small angles: $\cos^2\phi \approx 1$ and $GZ = GM\cdot\sin(\phi) = GM\cdot\phi$

Using an initial metacentric height of 2.0m, a wind speed of 10 knots that should produce a small heeling moment $\left(M_{10} = 5.751\cdot10^5\,Nm\right)$ and the values for Δ_{44}, A_{44}, B_{44} and C_{44}, as they can be obtained from Appendix III, equation (17) becomes:

$$8.62\cdot10^8\cdot\frac{d^2}{dx^2}\phi + 3.06\cdot10^7\cdot\frac{d}{dx}\phi + 1.269\cdot10^8\cdot2\cdot\phi = 5.751\cdot10^5 \qquad \textbf{(18)}$$

This linear second order differential equation can be solved analytically using simple mathematics. The roll angle as a function of time is given by:

$$\phi(t) = 2.266\cdot10^{-3}\cdot(1 - e^{-0.0185t}\cdot\cos(0.553t)) \qquad \textbf{(19)}$$

The graphical representation of this function of time can be obtained by any mathematical software and it has the shape of Figure 26:

:

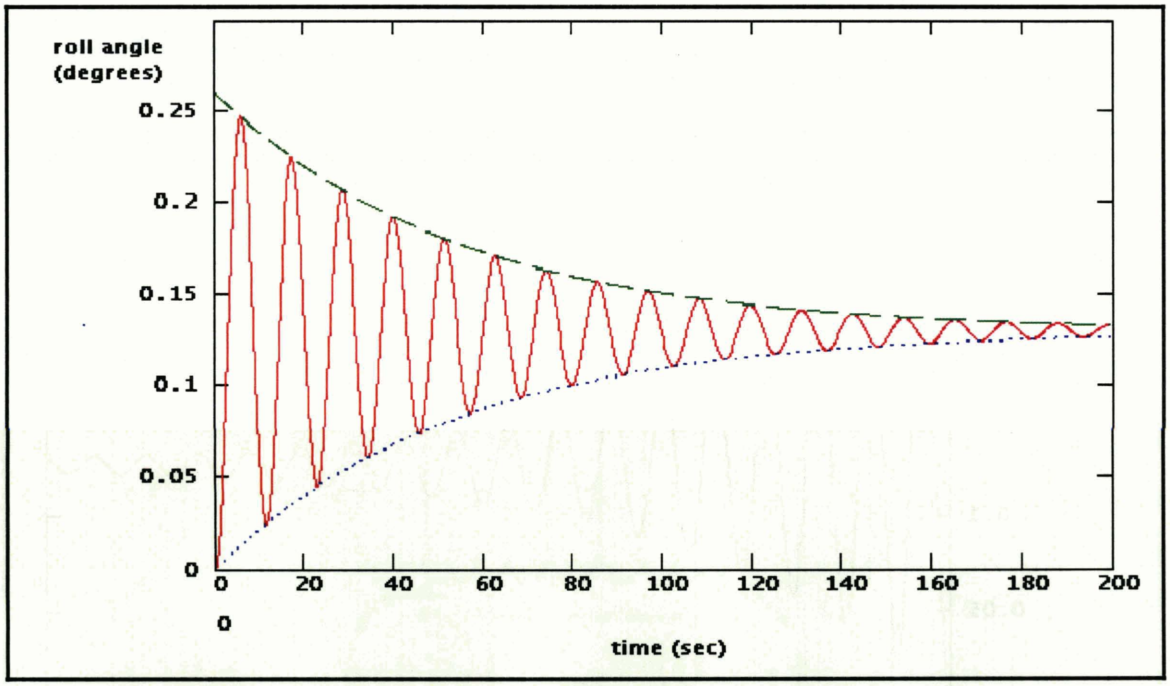

Figure 26: Graphical representation of analytical solution

The red line in the figure above represents the roll angle as a function of time, while the blue and green dashed lines represent the envelope that encloses the roll angle function. The dashed lines physically represent the roll angle amplitude decay ratio. For input values of cosine in equation (20) of 1 and -1 the green and blue lines take the analytical forms $\frac{M_{10}}{GM\cdot C_{44}}(1+e^{0.0185t})$ and $\frac{M_{10}}{GM\cdot C_{44}}(1-e^{0.0185t})$, respectively.

Furthermore, from equation (19), it can be derived that ω_n=0.553 radians per second and therefore the natural period of the system is: $T_n=\frac{2\cdot\pi}{\omega_n}=11.362\,\text{sec}$. Of great value is also the time scale $\frac{1}{0.0185}=54.05\,\text{sec}$ over which the oscillatory part of the roll amplitude will decay by a factor $\frac{1}{e}$.

4.1.5.2. Numerical Solution

The MathCAD code was also used, for the tumblehome ship with initial metacentric height GM=2.0m. The equation used for that run can be found in Appendix III and is also given below:

$$(\Delta_{44}+A_{44})\cdot\frac{d^2}{dx^2}\phi+B_{44}\cdot\frac{d}{dx}\phi+C_{44}\cdot\Pi(\phi)=M_{10}\cdot\cos^2(\phi) \qquad \textbf{(20)}$$

where $\Pi(\varphi)$ is the cubic spline created to fit the righting arm curve.

The MathCAD solution to this non-linear equation is graphically represented in the form of the roll angles versus time, in Figure 27:

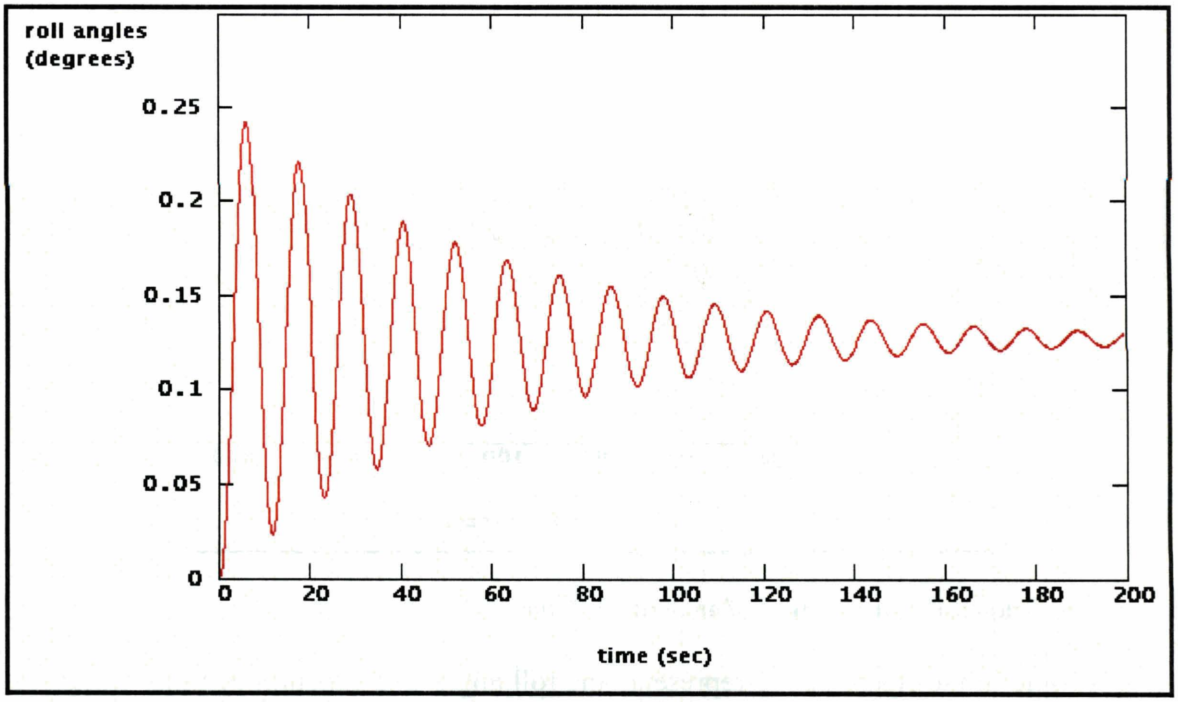

Figure 27: Graphical representation of the numerical solution

A comparison between the numerical and analytical results demonstrates:

- For long equilibrium times (t =1000secs) the code suggests a roll angle of 0.127 degrees, while the analytical solution gives a roll angle of $\lim_{t\to\infty}\left[\frac{M_{10}}{GM\cdot C_{44}}(1+e^{-0.0185t})\right]$=0.13, a discrepancy on the order of 2.3%.
- From the graphs one can observe that after 200 seconds the number of cycles will be equal for both cases.
- The local first maximum can also be evaluated for both cases. The maximum roll angle can be directly derived from the analytical and numerical roll angle functions, which turn out to be 0.225 and 0.242, respectively, thus an error of 7%.

These small deviations between numerical and analytical predictions can be attributed to the cubic spline approximation which only approaches reality in the vicinity of small positive angles. In fact, the tangent of the cubic spline at zero is smaller or greater than the initial metacentric height depending on the case.

4.2. Results when initial conditions are non zero

All calculations and graphs assume that the ship, before the wind gusts, was at rest, which means that the sea was calm and the initial angle of heeling and the initial angular velocity were zero. This however, is not realistic. A ship moving on the waves will gain some angle of inclination or some angular velocity under several circumstances. The following two case studies examine the results for dynamic case rolling angles when (I) there is an initial angle of inclination (caused i.e. by a turning of the ship or an angle imposed by damage) and (II) initial angular velocity (caused i.e. from a wave striking the ship from the side and providing the energy to the ship to start oscillation). These two cases intensify the problem if the application of the moment applied by the wind is in the same direction as the initial angular velocity or the initial angle of heeling. This will contribute to the generation of larger rolling angles and the reduction of the maximum wind speed that the ship can withstand without capsizing.

For the purposes of these case studies, the MATLAB© code created in previous steps, is used to run the combination of each hull form and each of the two initial metacentric heights for a range of speeds from 50 knots to 100 knots in increments of 2 knots. For the first case study an initial angle of six degrees of inclination is assumed. For the second case study an initial angular velocity of 0.1 rad/sec is examined. Those two values cannot describe the real and complex nature of movements of the ship in a rough sea, and they are arbitrary, but they are indicative of the deterioration of ship stability.

Tables and graphs of the resulting maximum rolling angles for both case studies in each of the above mentioned combinations are presented in Appendix VI. In the following sections, a comparison of the results for each hull and each initial metacentric height for the worst-case scenario of beam winds [$\theta=90^0$] is presented. The resulting graphs show that for all types of hull, and both initial metacentric heights, the ship becomes more vulnerable to capsize in the dynamic cases where the maximum roll angles are bigger for the whole wind velocity range when initial conditions are applied.[$\theta=90^0$].

4.2.1. Tumblehome Hull Form

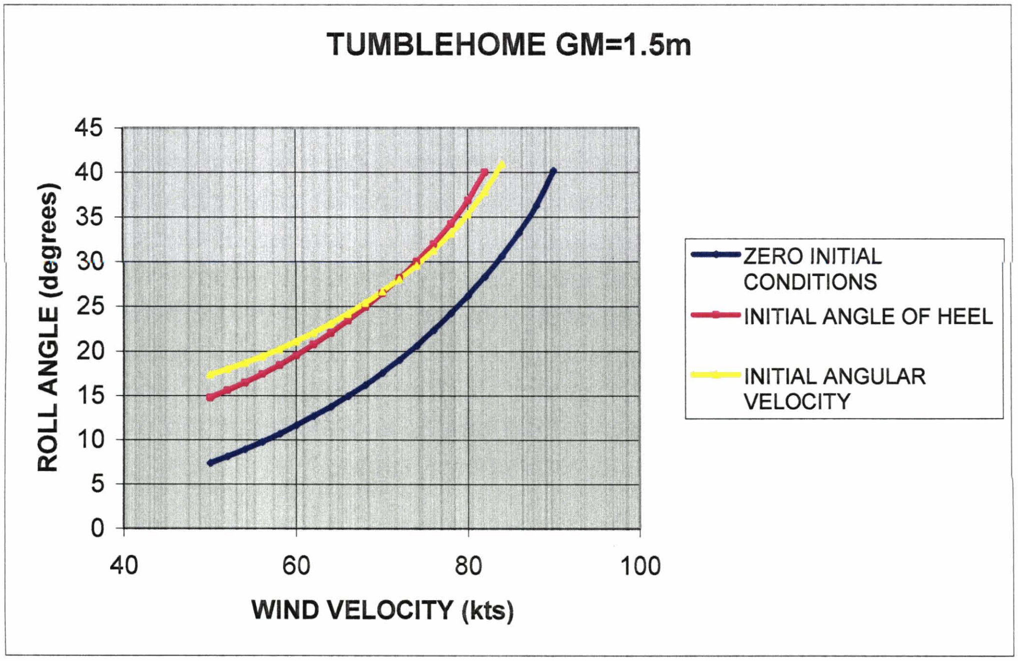

Figure 28: Comparison for different initial conditions (Tumblehome GM=1.5m)

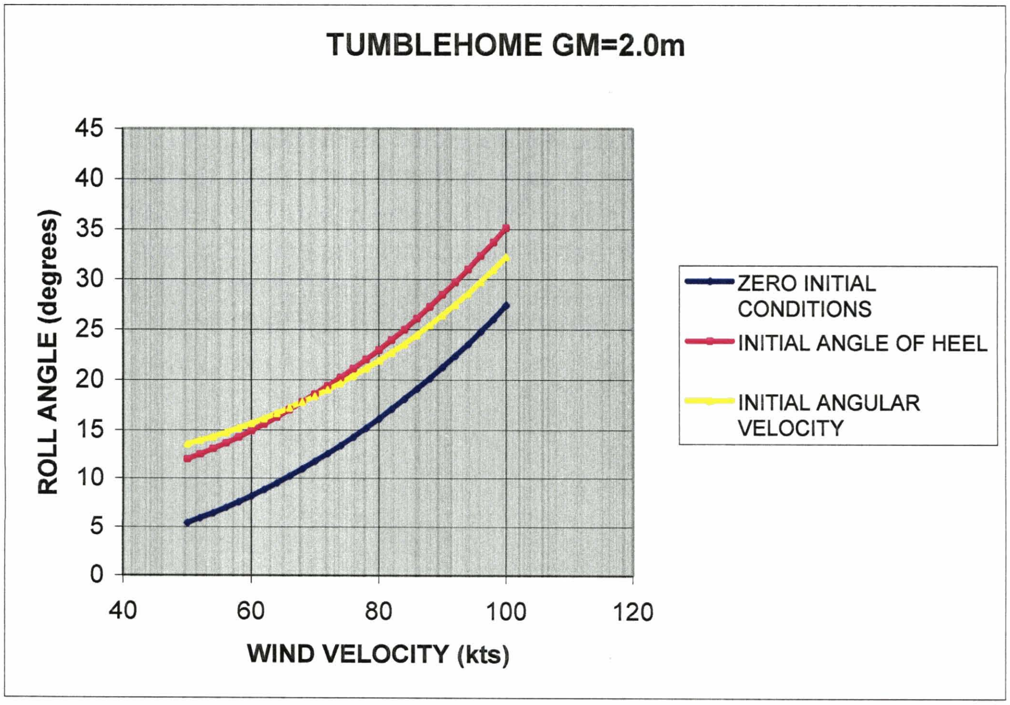

Figure 29: Comparison for different initial conditions (Tumblehome GM=2.0m)

4.2.2. Wall Sided Hull Form

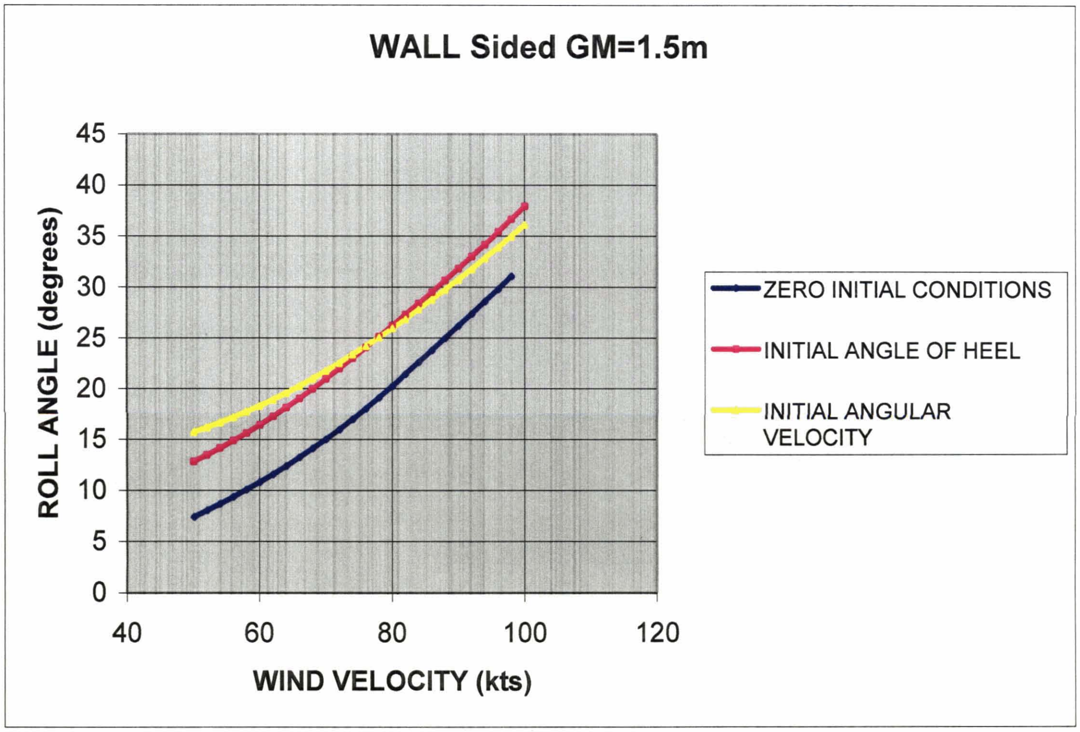

Figure 30: Comparison for different initial conditions (Wall Sided GM=1.5m)

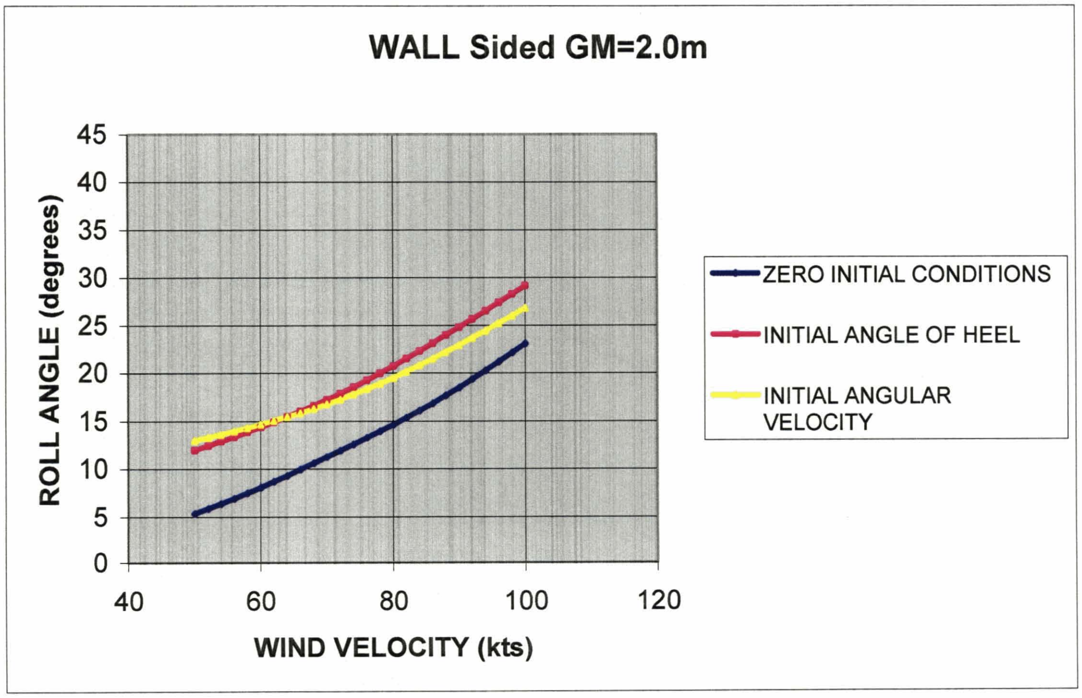

Figure 31: Comparison for different initial conditions (Wall Sided GM=2.0m)

4.2.3. Flare-Sided Hull Form

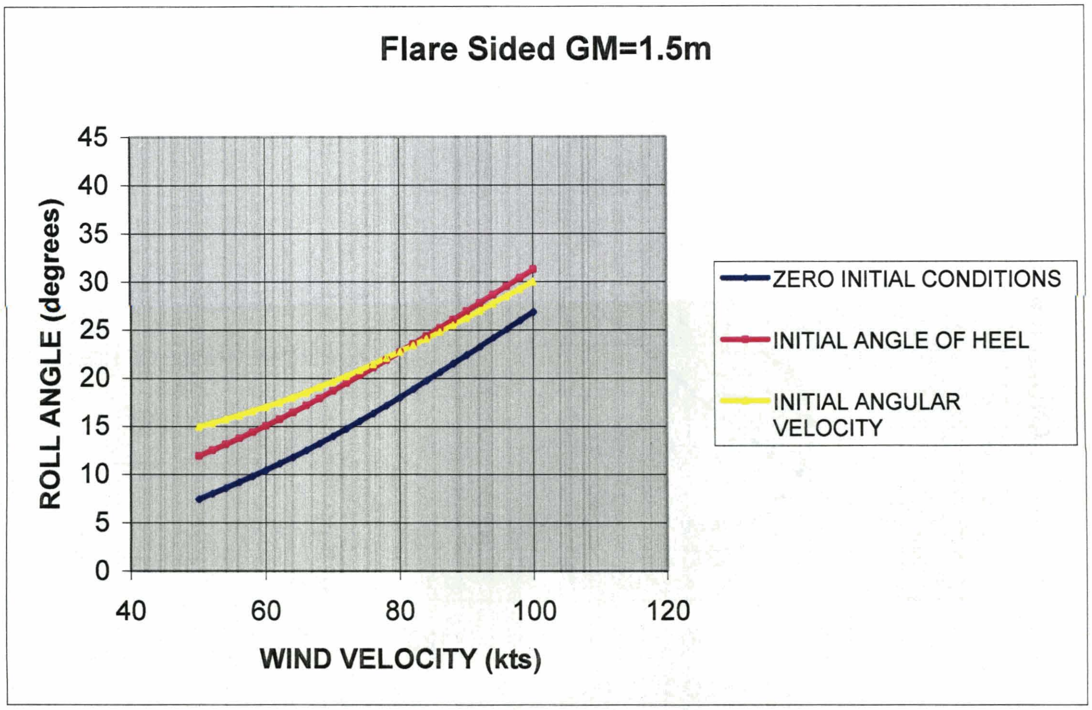

Figure 32: Comparison for different initial conditions (Flare Sided GM=1.5m)

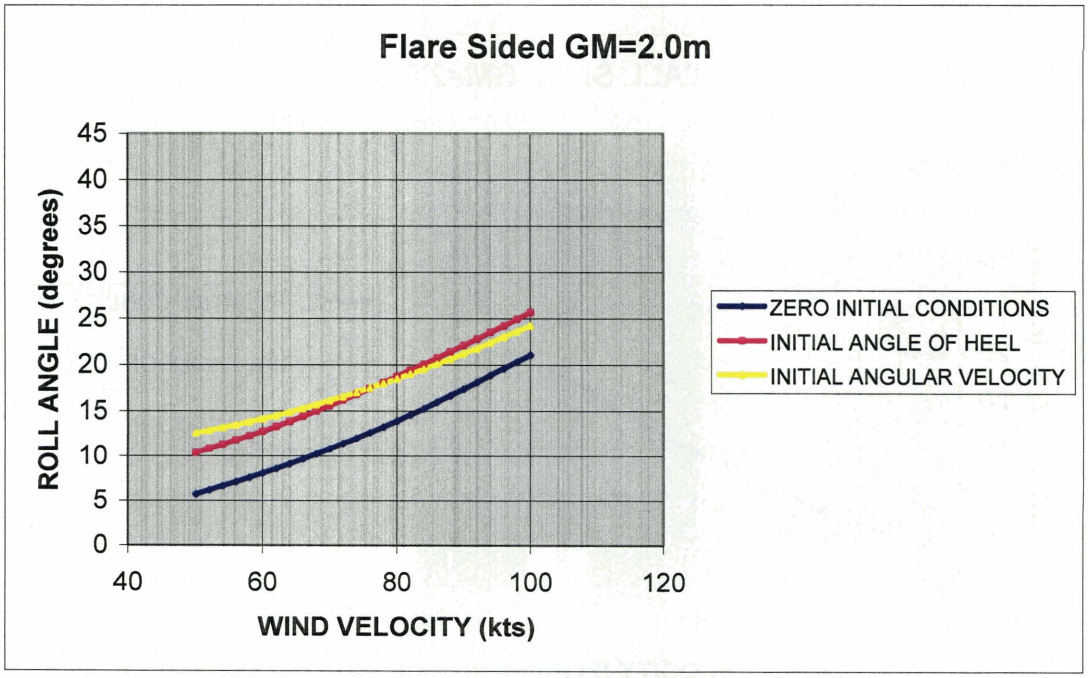

Figure 33: Comparison for different initial conditions (Flare Sided GM=2.0m)

Chapter 5: Future Steps

This thesis is a small part of a larger project whose purpose is to evaluate the behavior of tumblehome ships when underway in a stormy environment. As was earlier discussed, tumblehome ships are of special interest as they are in the future plans of many navies around the world for construction and acquisition.

In order to conduct the necessary analysis, assumptions are made. These assumptions are an unavoidable consequence of the lack of exact information concerning the shape of the hull of the new US Navy tumblehome ship, which is presently in the feasibility stage of design. Furthermore, this project neglects some of the details of the environmental conditions, as their complicated nature prohibits a more rigorous analysis. In fact, specialized work needs to be done in order to better evaluate the statistical weather conditions that dominate in the areas that the ship will operate.

The purpose of this chapter is to summarize the assumptions made in this thesis. This aims in helping future researchers to outflank the deterrents posed by these simplifications and to proceed with more accurate calculations as detailed information about the ship characteristics become available.

5.1. *Uniform wind*

During this project, the wind velocity profile was assumed uniform throughout the superstructure. As is shown in Figure 34, a wind, with nominal speed of 100 knots at a height of 10m, would not have the same value at all heights above the waterline but its value will follow the shape of the curve shown below:

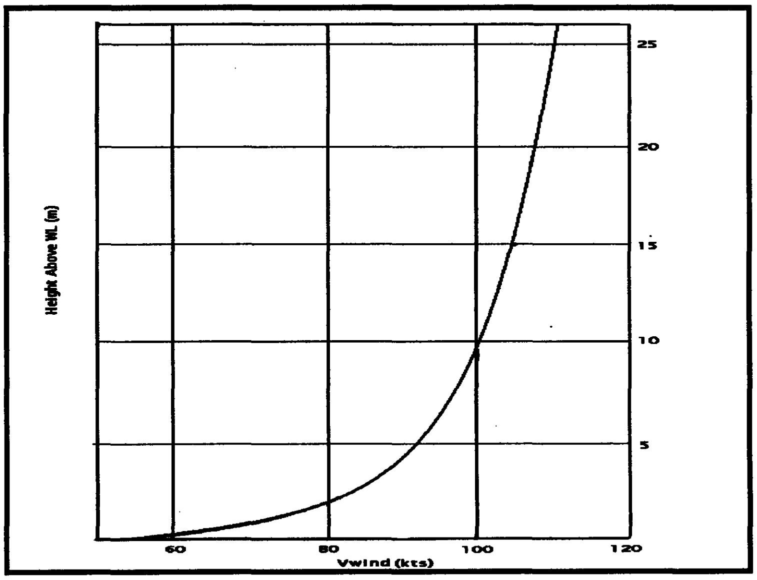

Figure 34 : Wind speeds (kts) at various heights (m) above WL (Nominal speed 100kts at 10m)

Therefore, in order to calculate exactly the forces and moments applied to the hull by the wind, one need to take the integral of the velocity profile over the hull. For that reason, wind velocity profiles should be constructed for several nominal wind speeds.

Therefore, in order to calculate exactly the forces and moments applied to the hull by the wind, one needs to take the integral of the velocity profile over the hull. Wind velocity profiles should be constructed for several nominal wind speeds.

A further step would be the refinement of the curve shown in Figure 34 to account for the cases where a ship is sailing in an area with large ocean breaking waves. The wind velocity profiles above those waves need to be studied using both numerical and experimental methods. This will contribute to the construction of reliable wind profile, which would probably deviate from the shape of Figure 34 in a region from the ship waterline to a height above the waterline that depends on the wave heights.

5.2. C_D calculation

The drag coefficient C_D used for the calculations was assumed to be equal to one ($C_D=1.0$). In reality, however, the drag coefficient is a function of angle of heeling of the ship. Apart from the height-dependent wind speed, the actual force applied on the hull by the wind is given by the formula:

$$F_{wind}(\phi) = \frac{1}{2} \cdot \rho_{air} \cdot U^2 \cdot A \cdot C_D(\phi) \qquad \textbf{(21)}$$

The lateral horizontal force applied by the wind, F_{wind} and the corresponding drag coefficient, C_D can be obtained by a wind tunnel test on a model of the actual ship. The moment produced on the ship model by the wind can be measured and by appropriate scaling of results from wind tests the full scale ship moment applied by the wind can be calculated. An example of an arrangement for tests in wind is shown in Figure 35[13]

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[13] IMO Intact Stability Code

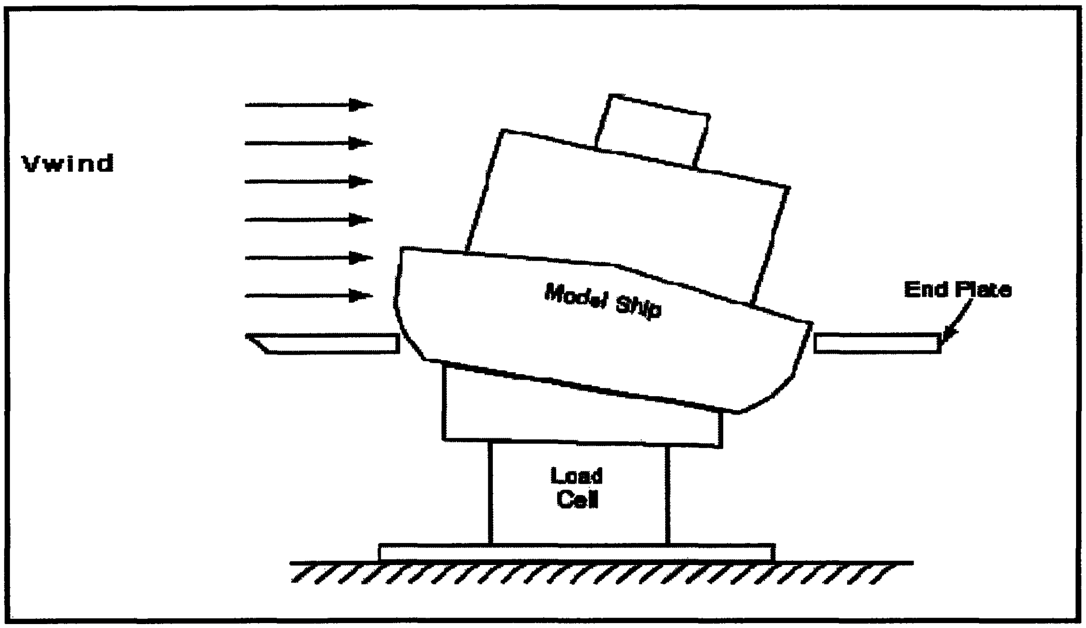

Figure 35: Arrangement for model tests in a wind tunnel

5.2.1. Model Set-Up

The ship model that would be used for wind tests should comply with the following:

- The model should copy the shape of the actual ship above the waterline
- All sharp corners in the actual ship should be resembled in the model in order to simulate separated flow
- Main fittings on the exposed decks and superstructures should be modeled and fitted properly
- The size of the model should be determined in order to make the blockage ratio to the wind tunnel less than five per cent [5%]. The blockage ratio is defined as the ratio between the lateral projected area of the model above the waterline and the area of the test section of the wind tunnel

5.2.2. Wind Characteristics

The wind speed should comply with the following:

- The minimum wind speed to perform tests should be over the critical Reynolds. number, after which C_D is constant (for the same angle of heeling)
- The wind speed versus height should model the atmospheric boundary layer over the ocean

- The effects of end plate (due to its shape, size, roughness, etc.) and of the gap between end plate and model should be minimized

5.2.3. Test Procedure

The lateral horizontal force F_{wind} and the heeling moment due to wind M_{wind} are obtained by the wind tunnel test measurements. C_D is calculated according to Equation (21), for the actual value of air density during tests.

Model tests should be carried out in compliance with the following:

- Before tests are carried out, the vertical and horizontal distribution of the wind speed at the model position should be verified.
- Tests should be carried out in upright position and at some heeling angles with appropriate increment to leeward and windward covering a sufficient range of heeling angles.
- The change of trim due to heel can be neglected.

5.3. Rising of Waterline as the ship heels

It is understood that as a ship heels to large angles the use of $\cos^2\varphi$ for the exposed area does not constitute a rigorous approach. In fact the exposed area can significantly deviate from this cosine function.

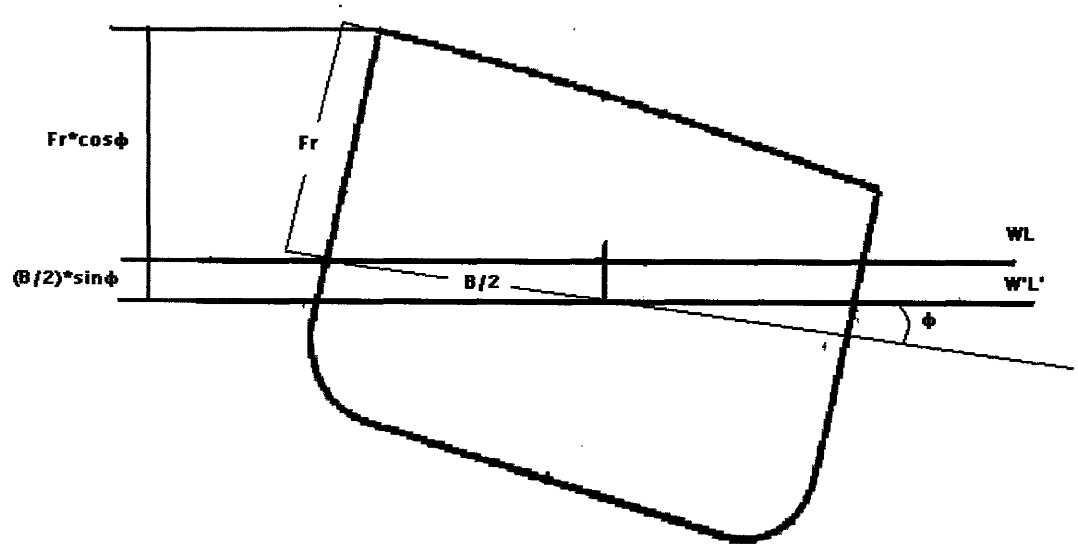

Figure 36: Projected to the wind area as the ship heels

As is shown in Figure 36, the projected area to the wind can be calculated by the sum of two components $Fr \cdot \cos(\phi) + \frac{B}{2} \cdot \sin(\phi)$.

where

Fr = is the freeboard of the ship before the heeling and

B = the beam of the ship at the new waterline

In order to calculate the refined roll angles in the case when the waterline is rising as the ship heels, the MathCAD code has been modified. In what follows, the governing equations will be derived and a comparison of the results between the two cases, when the waterline is rising and when it is not, will be conducted. The equations described in paragraphs 3.3.1, 3.3.2, 3.3.3.1, & 3.3.3.2 will be transformed in order to take into account the effect of the rising waterline. Equation (1) can be written as:

$$\mathrm{f1}(\phi, j) = \frac{1}{2}(H_j \cdot \cos\phi + \frac{B_j}{2} \cdot \sin\phi + H_{j+1} \cdot \cos\phi + \frac{B_{j+1}}{2} \cdot \sin\phi) \cdot (L_{j+1} - L_j) \qquad \mathbf{(22)}$$

where

- H_j represents the freeboard Fr and
- B_j represents the beam at various longitudinal positions

The force on a surface can then be derived using the transformed equation (6). The effect of the heeling, represented by the angle φ, is included in the $\mathrm{f1}_j$

$$\mathrm{F1}(\mathrm{Va}, \theta, \phi) = \frac{1}{2} \cdot \rho_{\mathrm{air}} \cdot C_D \cdot (V_a \cdot \sin\theta)^2 \cdot \sum_{i=0}^{20} \mathrm{f1}(\phi, j) \qquad \mathbf{(23)}$$

Equations (7) and (8) are transformed accordingly to the following:

$$\mathrm{d1}(\phi, j) = \frac{1}{2} \cdot \mathrm{f1}(\phi, j) \cdot (\frac{Hj}{2} \cdot \cos\phi + \frac{Bj+1}{4} \cdot \sin\phi + \frac{H_{j+1}}{2} \cdot \cos\phi + \frac{Bj+1}{4} \cdot \sin\phi + \mathrm{Draft} \cdot \cos\phi) \qquad \mathbf{(24)}$$

Equation (24) represents the moments applied to each of the trapezoids. The total moment applied to the hull by the wind can therefore be calculated as the sum of all the moments

$$\mathrm{M1}(V_a, \phi) = \frac{1}{2} \cdot \rho_{\mathrm{air}} \cdot C_D \cdot (V_a \cdot \sin\theta)^2 \cdot \sum_{i=0}^{20} \mathrm{d1}(\phi, j) \qquad \mathbf{(25)}$$

Again, the external moment applied by the wind is a function of φ, but this time is included in the expression of the moment and it is not proportional to $\cos^2\phi$. Consequently, the dynamic case equation which yields the roll angle now reads:

$$(\Delta_{44} + A_{44})\cdot\frac{d^2}{dx^2}\phi + B_{44}\cdot\frac{d}{dx}\phi + C_{44}\cdot GZ(\phi) = M1(Va,\theta,\phi) \tag{26}$$

with initial conditions:

$$\phi(0) = 0 \qquad\qquad \phi'(0) = 0$$

One has to give an input for the wind speed and direction in order to obtain the roll angles for the case when the waterline is rising as the ship heels. Figure 37 represents the difference between the two previously mentioned cases. The two codes were run for the tumblehome ship with the initial metacentric height of 2.0 meters, for a wind speed of 80 knots, with a direction of 90 degrees (lateral to the ship). The red line shows the roll angle versus time when the rising of the waterline is not taken into account, while the blue dotted line represents the roll angle produced by the contribution of the waterline rising. It is readily observed that in the case when the waterline is rising, the roll angles are amplified due to the larger area exposed to the wind.

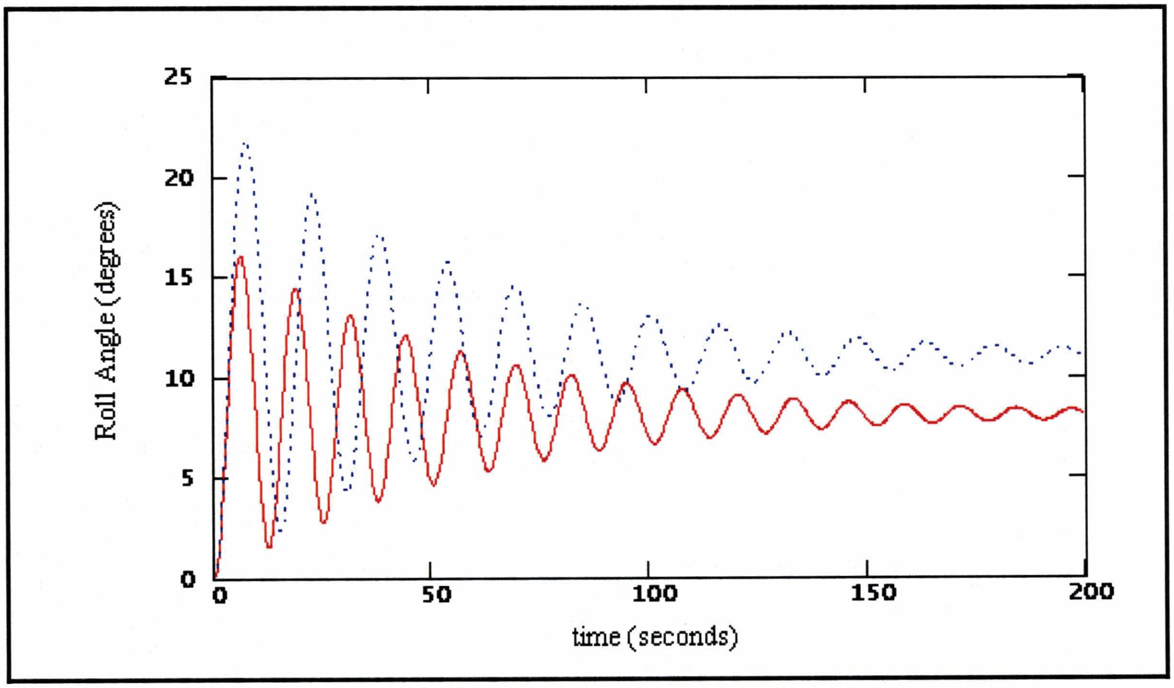

Figure 37: Effect of the rising of the waterline to the rolling of the ship

The enhanced code used to calculate the above cases is included at the end of Appendix III and it can be used to further investigate the roll angle for different ranges of wind speeds, different hull types and/or varying initial metacentric heights.

5.4. A_{44} B_{44} exact calculations

In the evaluation of the dynamic case rolling angle, the calculations of the added mass moment of inertia, A_{44}, and the damping coefficient, B_{44} were performed.

During analysis the ship examined was considered to have rectangular cross sections, with a beam B, where B is the beam of the ship at the waterline at each longitudinal position, and a draft T, which is assumed to remain constant for the entire length of the ship. These assumptions are a good approach to the calculations of the required coefficients, since the ships' offsets are unknown.

For additional accuracy, the ship offsets are needed. With the ship offsets in hand, exact cross sectional calculations of the ship at each longitudinal position are possible. A diagram of the two-dimensional added mass and damping coefficients for each cross section should also be constructed experimentally. Once both are available, integrating the 2-D cross sectional coefficients along the length of the ship using numerical methods, will generate the added mass moment of inertia, A_{44} and damping coefficient, B44 for the entire ship.

The added mass moment of inertia and damping coefficients used for calculations made in this project are estimates. The added mass moment of inertia, A_{44}, is a small portion of the ship moment of inertia Δ_{44}; consequently it would not play a dominant role on the change of the maximum roll angle.

Finally, B_{44} controls the number of cycles the ship will need to oscillate until it reaches the equilibrium angle, and its contribution to the maximum roll angle is also limited.

5.5. Forces and moments applied by the waves

It was first assumed that the ship was initially at rest. Subsequently, it was shown that the rolling angles are worse when an initial angle of six degrees or an initial angular velocity of 0.1 rad/sec was imposed. In reality, the magnitude of these initial conditions is determined by the environment in which the ship is moving. The dominant role is played by the waves. To define the forces and the moments that are applied on the hull of the ship, extended research on the wave velocity profiles should be conducted. In the simplified scenario that the waves are linear, the corresponding velocity profile can be directly obtained. However, in cases of large breaking waves, the velocity profile gets complicated and should be further studied, numerically and experimentally. Once a profile of velocities under breaking waves is obtained, then the forces and moments produced by wave-action can be calculated with more accuracy.

Chapter 6: Costs Associated with Capsizing

6.1. Causes of Capsizing

Bad weather conditions appear to be the most important single cause of ship losses. As it can be seen in Table 3, severe weather conditions are responsible for the thirty per cent of ship losses occurred in the decade 1989-1999.

Table 3: Total losses of ships (1989-1999)[14]

Nature of Casualty	*Bulk Carriers*	*Tankers*	*Other Vessels*	*Total (%)*
Collision	12	14	149	177 **(11%)**
Fire & Explosion	24	71	206	301 **(19%)**
Grounding	28	15	122	165 **(11%)**
Machinery	16	8	58	82 **(5%)**
Weather	64	37	372	473 **(30%)**
Other	39	26	307	372 **(24%)**
Total	**183**	**171**	**1214**	**1568**

Special caution should be taken when analyzing these results. Despite the observation that bad weather is the dominant factor there are a number of several other hidden reasons that can eventually lead to ship capsizing. Capsizing can in fact be the result of some specific existent environmental conditions in which a ship is moving combined with some human errors that take place, either before or during the trip. The exposure of the vessel to the extreme environmental conditions can therefore be the result of these human errors. Furthermore, human errors, imposed during the design process, weight growth modifications, loading or handling of the ship, can cause reduction of its reserve stability, resulting in a vessel more vulnerable to heavy weather where heeling moments are applied by the winds and waves, at the same time, and where synchronicity with waves can happened. Figure 38[15] schematically shows a fault tree of combined human actions and environmental difficulties that can lead to capsize.

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[14] Source: International Underwriting Association (IUMI Conference, London 2000)

[15] Source: Human Reliability And Ship Stability by Robert D,G. Webb & Tabbeus M. Lamoureux ,July 4,2003

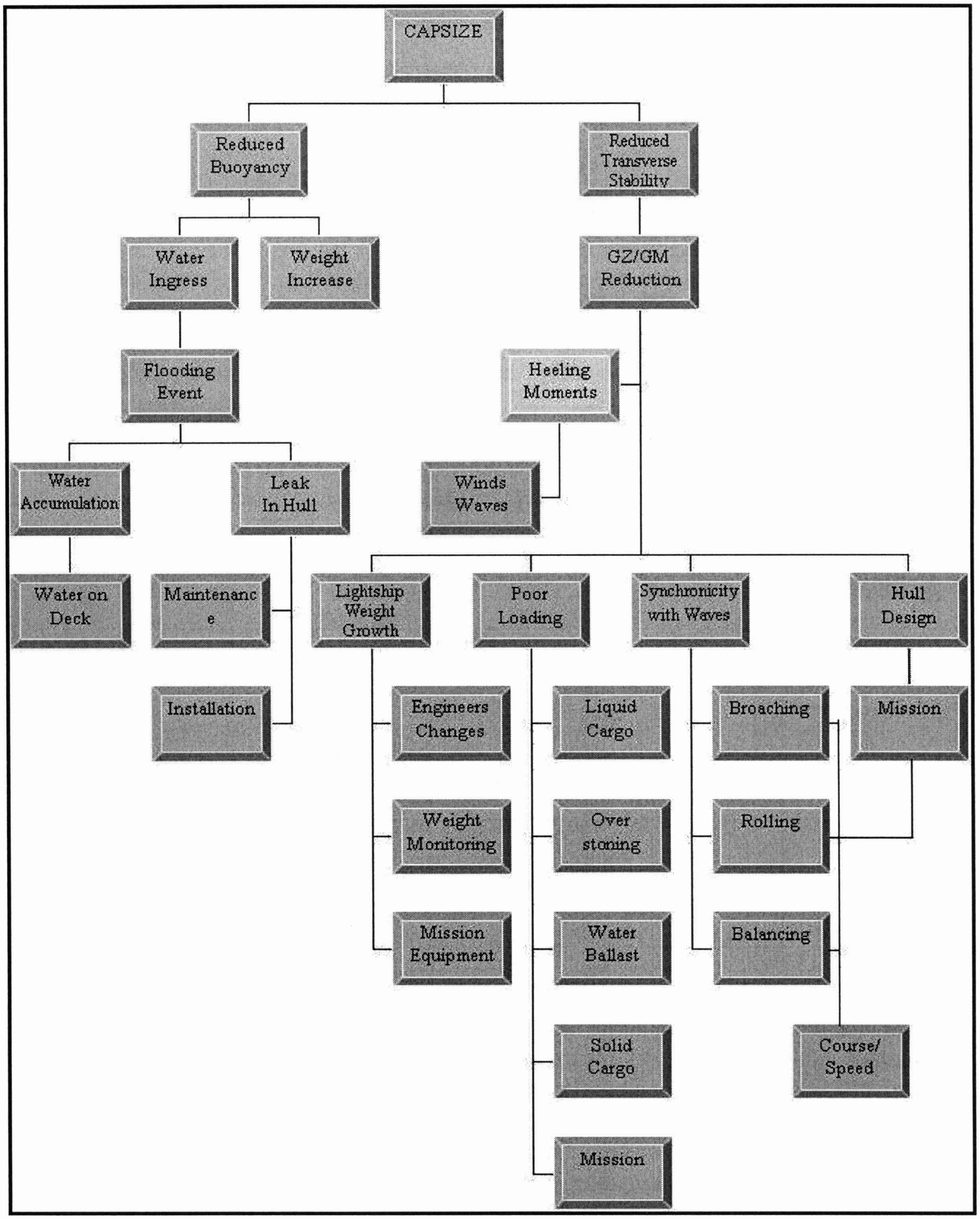

Figure 38: Fault tree for capsize

6.2. Identification of the Costs

The aspects of marine casualties, in terms of costs, associated with total loss of a ship will be briefly discussed. Thorough knowledge of costs is an important factor that should be taken into consideration when developing safety regulations and systems, or when characterizing the severity of vessel casualties or dealing with the risk assessment. The objective of this section is therefore to identify the prevailing cost variables, and to estimate their values where possible.

6.2.1. Costs Applied to the Shipping Industry

The direct cost of total loss of a seagoing vessel falls to the following categories:

6.2.1.1. Seafarers and Passengers

Some of the possible prospective costs are summarized below:

- Loss of life, personal injury or incapacitation. This can raise claims from the seafarers' party in order to have their livelihood assured.

6.2.1.2. Vessel Owners

The direct costs that an owner has to pay because of an accident that resulted in vessel total loss are:

- The physical loss of a vessel. This could be compounded by financial loss if:
    a) the ship has secure employment, and therefore a guaranteed income stream,
    b) the owner is accused and found guilty for negligence, thereby forfeiting any right for compensation. In general, the insured value of a ship is usually bigger than its actual market value.
- Higher hull and machinery (H&M) insurance premiums. These costs are applicable only if the ship-owner replaces the lost ship and/or if he owns other vessels.
- Loss of freight earnings from a voyage during which the loss occurs, assuming that the ship is on charter. The non-fulfillment of a charter can, depending on market conditions, involve a significant loss of revenues.
- Compensation claims for oil pollution-related environmental damage.
- Other third-party claims for compensation if an accident occurs. For example, such claims could originate from members of the crew or passengers as a result of personal injury or crew relatives in response to death of crew members. Likewise, when cargo is lost, the cargo owner, the charterer or the shipper may claim his rightful compensation.
- Higher subsequent P&I insurance premiums as a result of such claims, as mentioned above.
- Adverse public relations, although this depends on how well recognized the company is. For example, a large multinational oil company such as Exxon incurred significant adverse publicity after the 1989 oil spill from the "Exxon Valdez". On the other hand, few independent ship-owners are known to the general public, so these suffer little risk of consumer boycotts, or other direct

action against a casualty incident. The potential harm that adverse publicity can cause to a well-known corporation has driven many oil companies in distancing themselves from direct ownership of tankers in recent years. This has been achieved by providing independent ship-owners with long-term time charters. Also, unfavorable publicity can lead to a possible decline in the share price and capitalized value of the ship-owner if the involved, in a ship loss, is a well known company.

- Potential loss of confidence from charterers or shippers, if the owner is considered to be responsible for the loss of the vessel.
- Direct financial penalties, if the company is found to have violated national or state legislation (These penalties are generally more applicable to incidents including environmental damage rather than total losses, even though fatalities are more frequently associated with the latter case). Depending on the magnitude of the offence and which country's regulations have been breached the size of penalty may vary accordingly.
- The costs of litigation, in case the company gets sued for its actions, plus those of enacting any sentence imposed. These can be significantly large should a serious pollution has arisen.
- A lowering of the owner's credibility, potentially affecting the willingness of some banks to lend money to him afterward.

6.2.1.3. Charterers / Shippers / Cargo Owners

Although this category has not full access to the ship loading or the conditions in which a ship operates, they might suffer possible costs that are related with:

- The potential loss of a cargo. This can have serious consequences if:
  - a) The commodity being carried possesses a high inborn value.
  - b) Its loss prevents the operation of an industrial facility to which it is to be delivered. (This can apply even if the cargo has a relatively low unit value, e.g. iron ore).
  - c) The charterer or shipper does not insure his cargo.
- Adverse publicity if the charterer is widely known. However, many charterers are not necessarily largely known outside the shipping industry community; furthermore, to minimize the risk of suffering bad publicity, some large organizations charter under names that differ from their respective prime corporate identity.

6.2.1.4. Classification Societies

The classification societies have suffered much obloquy for their alleged "complicity" in some of the worst shipping casualty incidents of recent years. Classification societies that ignore international regulations face, consequently, the following costs:

- Adverse publicity if a vessel is in an accident arising from a serious defect that should have led to the society withholding class until it had been rectified.

- Third-party compensation claims, if the society has been negligent or has willfully failed to impose class requirements, resulting in an accident. The magnitude of such penalties varies, depending on the severity and nature of the incident and the legal jurisdiction under which the claim is being pursued. However, societies generally include in any contract with their clients a clause releasing them from liability.

6.2.1.5. Shipbrokers

Apparently, whether a broker is even involved in a voyage that results in a casualty incident depends on the type of ship and whether its owner is not otherwise able to deal directly with a charterer or shipper to secure employment for his vessel. A shipbroker can suffer costs relating to damage caused by a substandard ship if:

I. He fails to advise the buyer or the charterer of a ship that he is merely acting on behalf of the vessel owner, rather than acting as a principal himself, when relaying information and expressing opinions about the ship.
II. He does not notify the charterer of any obvious defects that the vessel may have which are subsequently found to have been responsible for any loss or damage.

In such situations, the broker is deemed to have acted negligently and the costs that he will face in a case of total loss of the vessel are coming from:

- Compensation claims from charterer / cargo owner.

6.2.1.6. P&I Clubs

These tend to suffer a higher incidence of compensation claims if a club has provided P&I cover to the owner of a substandard ship. Such vessels are associated with a greater likelihood of accident than well-maintained, well-operated tonnage. Some clubs exercise strict risk assessment procedures, including the inspection of ships for which their clients seek P&I cover. However, others rely merely on proof being available that the ship complies with class requirements. The costs brought upon P&I clubs are:

- Remuneration of third-party compensation claims for loss of life, personal injury, loss of cargo & environmental damage if the vessel owner forfeits his right to limited liability.

6.2.1.7. Marine Underwriters

Companies that provide hull & maintenance insurance suffer various costs in the event of an accident. These include:

- Reimbursing the owner for the insured value of a ship that has been an actual total loss.

6.2.1.8. Banks and Financial Institutions

Past experience shows that some high profile banks have let themselves become excessively exposed to bad credit risks by lending to owners of questionable merit and credibility. However, many other banks take a more responsible stance and exercise stringent controls on the tonnage on which they will lend and the owners to whom they will provide the respective funds. Depending on how careful they are, banks can in theory face the following costs:

- Financial loss if a vessel on which it has given a mortgage sinks and the owner is found to have been negligent, so forfeiting any right to compensation. However, in practice, the bank would have required some guarantee as a condition of the loan, so should recover the balance of the mortgage regardless of the loss of the ship.
- Financial loss if a vessel owner proves to be insolvent.
- Direct fines, but only if the bank is actively involved in the operation of a ship, rather than being a mere lender. However, this situation could change if the bank had reason to foreclose on a mortgage and thereby became a lender in possession. Furthermore, under leasing arrangements, a bank is effectively the owner of the ship. As such, it could therefore be liable to any penalties imposed.

Table 4 summarizes the costs described above:

Table 4: Direct costs of ship total loss for respective parties

Party	**Potential Costs Incurred**
Seafarers / Passengers	*Loss of life / personal injury*
Ship-owners	*Loss of insured vessel*
	Higher H&M insurance
	Third-party compensation claims
	Higher P&I insurance
	Adverse publicity
	Financial penalties
	Litigation
	Reduction in credit rating
Cargo Owner / Charterer/ Shipper	*Loss of cargo*
	Possible disruption to operations at facility to which cargo is being delivered
	Adverse publicity
Banks	*Loss of vessel*
	Financial penalties
Marine Underwriters	*Payment of insured value of vessel provided that loss is not proven to have resulted from ship owner's negligence.*
P&I Clubs	*Payment of third-party compensation claims for loss of life, personal injury, loss of cargo & environmental damage.*
Classification Societies	*Adverse publicity*
	Financial penalties
Shipbrokers	*Compensation claim from charterer / cargo owner*

6.2.2. Costs outside shipping industry

The cost of ship losses has also implications on the society through the damage caused to the environment. The estimation of damage to the maritime environment through an oil or chemical discharge and whom it may concern is a very difficult task in the present state of knowledge. But it is almost certain that would cause:

- physical effects on the biological environment
- lost recreational values
- effects on the tourist industry
- economic consequences for the fishing industry
- cost of restoration measures

6.3. Values of several damages

As it becomes evident from the previous sections, calculating the costs associated with the total loss of the vessels can be an extremely complicated procedure. Taking into account that the collection of cost data is a cumbersome and time-consuming task, their calculation is almost impossible for anyone having no direct access. In fact the ship-owners' cost data can be characterized as trade secrets and therefore kept unexposed to the general public. Therefore, the various costs involved will be estimated as a whole, as its categorization to the several related parties is beyond the scope of this thesis. Hence, based mainly on published and web sources, this study will try to collect statistical data of several accidents under extreme weather conditions that led to the total loss of the ship. Furthermore, this data will be analyzed, and approximate values for each case will be applied in order to calculate an estimate of the total loss cost of a vessel. In future steps, when available cost data is available, the methodology and formulas derived below can be enhanced, in order to give more accurate estimations.

All costs quoted are 2006 prices and expressed in US dollars. The inflation rate used to modify some of the prices to present value of money (NPV – Net Present Value) was assumed to be two percent (2%).

6.3.1. Value of Life

Any attempt to put a value on human life runs into a number of difficulties, the most fundamental of which is the objection that the value of life cannot be measured in monetary terms. However, as a part of everyday performance of both the legal system and the insurance industry, such evaluations must be, and are regularly carried out. An extensive literature exists on the value of human life and only the adequate price estimates will be quoted.

The value of human life is measured in two ways: a) in terms of a person's expected lifetime earnings and b) in terms of industry's expenditure on safety measures per life saved. The first method gives an estimated value of the life of a seaman to be about 1.2 million US$(1980); the second method estimates the value to be 1.4 million US$(1980)[16]. The value of human life lost in a road accident can be calculated, for several countries and these costs are given below:

- Great Britain[17]: 902,500 Great Britain Pounds per fatality (1994)
- United States: 2,600,000 US dollars per fatality (1994)
- Canada[18]: 2,900,000 Canadian dollars per fatality (1998)
- Australia: 1,500,000 Australian dollars per fatality (1996)

In the following table ,Table 5 all the above are converted to US dollars (2006), using a common inflation rate of 2% and a conversion rate between different currencies as it was on April, 21 2006.The average cost of human life per fatality coming from the different methods will be assumed for the calculations carried on from that point:

Table 5: Calculation of cost per fatality using different estimations

	Initial Value	Value(2006)	Conversion Rate (21-Apr-2006	Value(2006) in USD
Method 1	1.4mUSD(1980)	2,342,785 USD	1.0000	$2,342,785
Method 2	1.2m USD(1980)	2,008,101 USD	1.0000	$2,008,101
Method 3	0.9m GBP(1994)	1,144,588 GBP	1.7783	$2,035,432
Method 4	2.6m USD(1994)	3,297,428 USD	1.0000	$3,297,428
Method 5	2.9m CUD(1998)	3,397,812 CUD	0.8798	$2,989,395
Method 6	1.5m AUD(1996)	1,828,491 AUD	0.7378	$1,349,061
Average				**$2,337,034**

The cost of injuries is less a matter of opinion than the value of a life. However, the lack of knowledge on the distribution of the severity of injuries makes a detailed analysis impossible. A rough average estimate from references [9], [10], [13] and [14] indicates almost 1/30 of the cost of a fatality to be spent for an average injury. Therefore a 77,901 US$ per injury will be used for further calculations. When using this estimate, it is assumed that the severity distribution of injuries in maritime casualties is the same as in road accidents.

6.3.2. Value of Damage to Property

The second-hand market value is generally assumed to be the best indication of the value of a vessel. This viewpoint is adopted here and the values of ships totally lost are taken to be equal to their second-hand prices. Published ships sales in the second-hand market were collected. Reference [11] summarizes the data collected for the sales of second hand

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[16] Studies on Ship Casualties In the Baltic Sea, P.Tuovinen, V.Kostilainen- 1984

[17] Accident costing using value transfers, Juha Tervonen,,1999

[18] Transportation Cost and Benefit Analysis-Safety and Health Costs, Victoria Transport Policy Institute

ships for the years 2002-2006 (sales of the first two months of 2006 are included). The total number of ships sold each year, the total deadweight tonnage they weighed and the total amount of money spent for the acquisition of these ships are presented in two tables. Table 6 presents the values for bulk carriers and Table 7 presents the values for tankers. Bulk carriers, Ro-Ro, Passenger ships, and Containerships are included in the first category. Tankers, Liquefied Petroleum Gas Carriers (LPG) and Liquefied Natural Gas Carriers (LNG) fall into the second category.

Table 6: Total outlays in 2006 US $ for bulk Carriers (Ro-Ro, Passenger Ships, Containerships incl.)

Year	Number of Vessels Sold	Total Outlays in current year US$	Total Outlays in 2006 US$	Total Deadweight	US$/ton
2002	724	5,288,660,000	5,724,615,667	28,724,712	199.29
2003	931	8,903,350,000	9,448,306,247	33,625,481	280.99
2004	1174	17,590,000,000	18,300,636,000	40,447,590	452.45
2005	847	15,386,630,000	15,694,362,600	33,165,379	473.22
2006	140	2,909,470,000	2,909,470,000	5,979,308	486.59
				Average	**378.51**

Table 7 : Total outlays in 2006 US $ for tankers (LNG, LPG incl.)

Year	Number of Vessels Sold	Total Outlays in current year US$	Total Outlays in 2006 US$	Total Deadweight	US$/ton
2002	291	3,340,960,000	3,616,362,549	20,941,191	172.69
2003	531	10,662,590,000	11,315,225,809	45,792,468	247.10
2004	667	16,398,000,000	17,060,479,200	57,501,260	296.70
2005	549	16,278,910,000	16,604,488,200	39,485,311	420.52
2006	95	3,468,280,000	3,468,280,000	8,493,165	408.36
				Average	**309.07**

The total value of the ship per ton will be assumed as the average of the price for each year, converted again to 2006 US$ value. This assumption, while not realistic, is a good first approximation that can replicate the market prices cycle. Another assumption is that the actual price of a second hand ship that would replace the lost vessel when total loss occurred should differ from the price derived from the data collected for the years between 2002 and 2006. The fluctuations in the shipping market lead to a 5-year data collection of second hand ship prices in order to reflect the average price per ton. The number of total losses due to bad weather conditions between years 1960 to present, for all types of ships, is about 1890 and it would be extremely difficult to assess the second-hand value of each ship separately by taking the known prices of ships of the same type and about the same age and size and then taking the average. The method of taking the average of the price per ton and then derive a formula, characteristic of the costs associated with the total loss, would not be very accurate but it would be indicative and useful.

6.3.3. Value of Environmental Damage

The determination of the economic value of damage to the maritime environment through an oil or chemical discharge is a very difficult task in the present state of knowledge. As the existing data does not provide any information about the pollution magnitude of each case, this study will calculate the oil spilled by tankers to the ocean. We will consequently make the assumption that in any accident that caused pollution, the whole cargo was oil and try to evaluate the cleanup costs which give an indication of the magnitude of the economic values involved. According to reference [9], the total cleanup costs were about 46,000,000 2006 US$ for 5,500 tons of oil spilled, thus 8,300 US$ per ton. Unfortunately all the other physical effects due to environmental pollution, described in paragraph 6.2.2, can not be evaluated because the information obtained on the economic consequences of the oil spills which have taken place in connection with the ship casualties is insufficient and no detailed analysis is possible at this stage. It can be mentioned however that the recreational values lost due to the closure of a beach in a tourist site during summer period are estimated to be about 30 to 40 millions US$. But, these costs cannot be a part of the analysis as the knowledge of the beach closures due to pollution caused by an accident is inadequate.

6.3.4. Value of Cargo

Cargo damage and its associated cost can only be defined after specifying the case of ship accident and the freight. In this thesis cargo damages will therefore be evaluated using the following 2-step procedure: 1) Cost per ton of some of the major goods carried overseas will be assigned using web sources[19]. 2) Then, an average of these prices will be multiplied by the average deadweight of all the ship lost in order to calculate a non accurate but indicative estimate of cargo costs due to a loss.

Table 8, demonstrates the prices of some of the seaborne commodities carried by bulk carriers, containerships and general cargo ships, in US $ per metric ton. It should be noted that the following conversions hold:

1 bushel = 35.24 liters = 27.215 kilograms. Also,

1 box = 18.14 kg

1 pound = 0.454 kg

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[19] http://markets.usatoday.com/custom/usatoday-com/html-commodities.asp

Table 8: Major commodities carried bulk carriers, container and general cargo ships

Commodity	Price in US$ per x-units				kg per x-unit	Price in US$ per mton
Cocoa	0.73	per	1	pound	0.454	1,617.53
Tea	1.47	per	1	kg	1	1,470.00
Coffee	0.8276	per	1	pound	0.454	1,824.55
Sugar	0.099	per	1	pound	0.454	218.26
Rise	218.52	per	1	mton	1000	218.52
Wheat	130.44	per	1	mton	1000	130.44
Soybean	238.58	per	1	mton	1000	238.58
Corn	2.485	per	1	bushel	27.215	91.31
Cotton	0.5252	per	1	pound	0.454	1,157.87
Wool	7.11	per	1	kg	1	7,110.00
Fish Oil	718	per	1	mton	1000	718.00
Coconut Oil	617	per	1	mton	1000	617.00
Bananas	7.76	per	1	box	18.140	427.78
Orange juice	1.4525	per	1	pound	0.454	3,202.21
Poultry Meat	1218.25	per	1	mton	1000	1,218.25
Meat Livestock	2617.71	per	1	mton	1000	2,617.71
Bovine Meat	4172	per	1	mton	1000	4,172.00
Pork bellies	0.7938	per	1	pound	0.454	1,750.03
Thermal Coal	55	per	1	mton	1000	55.00
Copper	3.08	per	1	pound	0.454	6,790.24
Iron Ore	65	per	1	mton	1000	65.00
Aluminum	1.259	per	1	pound	0.454	2,775.62
Average						**1,749.36**

Table 9, shows the prices, in US$ per metric ton, of goods carried by tankers or LNG ships. For clarity of conversion it should be mentioned that the following values where used:

1 gallon = 3.7854 liters

1 barrel= 42 gallons

Gasoline Density = $0.73722\frac{kg}{lt}$

Crude Oil Density = $0.847\frac{kg}{lt}$

Brent Oil Density = $0.873\frac{kg}{lt}$

Natural Gas Density = $0.41\frac{kg}{lt}$

Table 9: Major commodities carried by tankers and LNGs

Commodity	Price in US$ per x-units				kg per x-unit	Price in US$ per mton
Brent crude	74.57	per	1	barrel	134.660	553.77
Crude oil	73.95	per	1	barrel	138.790	532.82
Natural gas	210	per	1000	m^3	410.000	512.20
Unleaded gasoline	2.181	per	1	gallon	2.791	781.44
Average						**595.05**

6.4. Calculations

This section deals with the calculation of the cost relating to ship losses. The presented data was collected using a trial version of the software SEA-WEB®, developed by Lloyds. The search criteria posed, concern the total ship losses in bad weather conditions for the period between years 1960 and 2005. The outputs of this search were:

- Name of the lost ship
- Date of loss
- Number of people killed
- Cargo that the ship carried
- Deadweight
- Gross tonnage of the ship during the loss
- Whether there was a pollution or not

The extracted data was analyzed and organized in tables, which are presented in appendices VII through X. Table 10 summarizes that data:

Table 10: Cumulative data for ship accidents per type for the period 1960-2005

	Number of Accidents	Deadweight (mton)	Gross Weight(mton)	Number of Killed/Missing)
Bulk Carriers	75	3261035	1807729	797
Containerships	8	56882	50823	68
Passenger/Ferry/RoRo	39	84697		2541
General Cargo	626	2923869	1814262	2371
Tankers	68	837026	493840	319
TOTAL	***816***	***7163509***		***6096***

Figure 39 demonstrates that bulk carriers and general cargo ships lost under heavy weather conditions represent the largest proportion in terms of deadweight percentage. The loss of tankers follows by 12%, while the loss of Passengers ships/Ro-Ro/Ferries and containerships is rather uncommon (~1%).

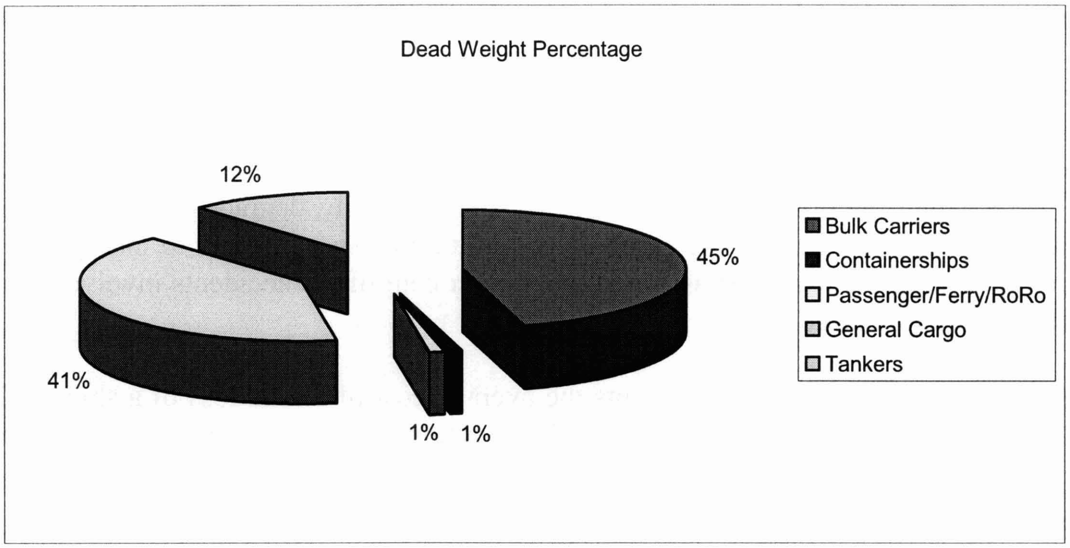


Figure 39: Deadweight percentage of totally lost vessels per ship category

From a number of casualties perspective (Figure 40), however, Passenger Ships/Ferries/Ro-Ro are responsible for the largest portion (42%). These are followed by General Cargo ships (39%) which increased in proportion due to the great number of accidents that happened in this category of seagoing vessels during the last 50 years. Tankers, Bulk carriers and Containerships contribute to only a small portion of the total fatalities (~19%).

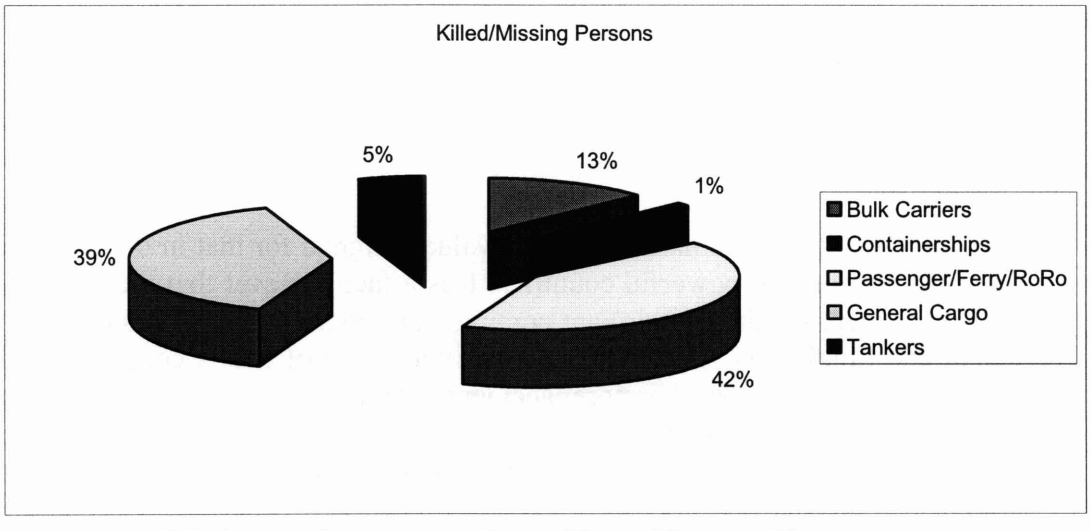


Figure 40: Killed/Missing people percentage due to ship total loss per ship category

In order to calculate the average costs, as previously mentioned, two major categories for the second hand prices will be assumed. Bulk carriers, containerships, passenger ships, ferries, Ro-Ro and general cargo ships will be handled as they have the same second hand prices. The same assumption will be employed for tankers, LNG and LPG ships. In dealing with the lost cargo the same two categories will be used, with the only difference being that for ships carrying passengers there is no cargo. For all the other ships their gross tonnage will be assumed to be the weight of the lost cargo. Furthermore a comment is due on the pollution related costs of ships carrying oil. Generally speaking one can avoid the consideration of pollution issues as some of lost oil carrying ships rest on the ocean bed with their tanks sealed. It is generally accepted, hwovere, that the highly corrosive saline environment of the ocean water gradually degrades the ship with the great possibility of oil to escape and create a pollution issue. In order to incorporate this issue in our analysis it will be assumed that 50 per cent of the accidents involved tankers caused a pollution issue.

The following table, Table 11, presents the average cost of a total loss of a ship, in 2006 US$, for each category. The previously mentioned assumptions were used in a MathCAD® code that calculated the total cost. The details of these are presented in Appendix XI.

Table 11: Average costs per accident for each category

	Human Life Cost	*Vessel Cost*	*Cargo Cost*	*Clean-Up Cost*	*Total*
Bulkcarriers	24,830,000	16,460,000	42,160,000	n/a	**83,450,000**
Tankers	10,960,000	3,804,000	4,321,000	30,140,000	**49,225,000**
Containerships	19,860,000	2,691,000	11,110,000	n/a	**33,661,000**
General Cargo	8,852,000	1,768,000	5,070,000	n/a	**15,690,000**
Passenger Ships	152,300,000	822,000	n/a	n/a	**153,122,000**

6.5. Assumptions & future steps

This section summarizes the assumption made in our calculations and aims in pointing out the simplifications made during the calculation procedure. The lack and inaccessibility of data were the primary reasons that led to the following treatement. Thus, this procedure may contain inaccuracies that should be improved as more data becomes available. The major assumptions made are:

- The value of life is calculated using the value assigned for that in the richest and the most economical powerful countries. It is a fact however that the majority of seamen (except for the captain) are coming from poor countries (Eastern Europe, China and South-East Asia, Africa) where the value of life is considerably less than the derived one. Furthermore, accidents are assumed to happen in countries that have no strong regulations that would prevent the bad handling of the ship in the altar of the ship-owner's profit (overloading, indifference of ship condition etc.)
- The value of second hand price is derived from the past five year data which cannot give with great accuracy the value of a ship sunk fifty years ago. Also the analysis made treats all the types of ships as two major categories and the value derived is based on the deadweight tonnage as previously described.
- The environmental related cost is calculated as the clean-up costs due to the oil spills. Such a physical disaster is usually associated with implications on tourism, fishery or wild life. These additional implicit costs are not included in our

analysis. Finally, the percentage of ships causing environmental pollution (fifty per cent of the tonnage carried is spilled to the ocean) was arbitrarily chosen.
- The cargo's value is taken as the average of some products usually carried through the ocean routes and the gross tonnage of the commodities carried is multiplied by the average prices of these commodities.

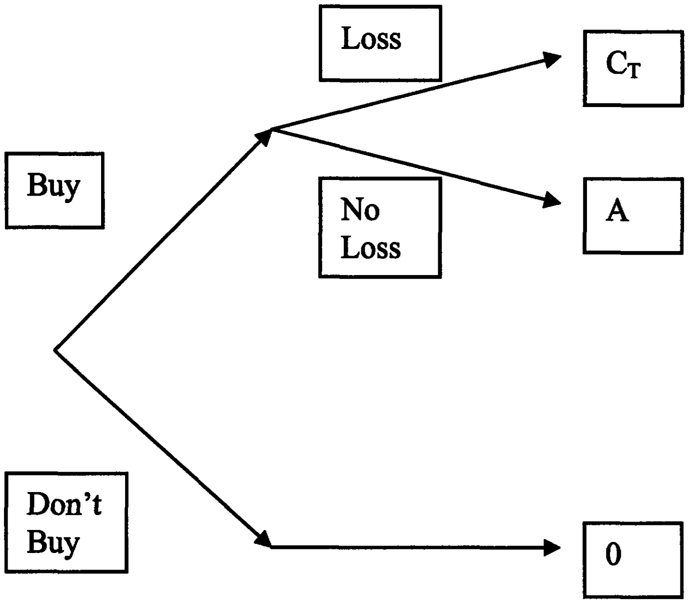
It should be noted that the accurate procedure of finding the average costs of total losses of ships during the last five decades is completed through the following steps:

- Access each case separately
- Calculate the costs associated with this loss
- Convert the total cost of each case in 2006 money value
- Divide the total cost of all ships' losses with the number of cases to find the average per ship cost of each case

6.6. Conclusions

Throughout Chapter 6 we presented estimates of the costs associated with a potential ship loss. In what follows we demonstrate how these estimated costs can be used for decision making processes, either by ship owners, insurance companies, or even ship manufacturers.

The decision tree for such an evaluation process is:



where:

- x is the probability of a fatal accident happening during the designed lifespan of the of a ship, Y.
- C_T is the net present value of the total cost associated with the ship loss and the profits that the ship has contributed until that time.
- P_j is the profit made by the ship in year-j
- The inflation rate is assumed to be constant throughout the years and equal to i, while the initial capital investment for buying the ship is denoted by D.

The earnings in today's money can be calculated as:

$$A = -D + \sum_{1}^{Y} \frac{P_j}{(1+i)^j}$$

and the expected monetary value of the decision will be

$$EMV = \left[(1-x)\cdot A + x\cdot C_T\right]$$

Consequently, one can make an investment or insurance decision based on the resulting EMV. In general positive EMV's denote an investment opportunity where profit is made, whereas negative EMV's suggest an incurred cost. It must be noted however that the personal preference (risk aversion) of the decision maker has not been included in our analysis. There are however advanced theories (utility theory) that can improve the previous decision process.

The above simplified analysis demonstrates the value and use of the estimated costs associated with a ship loss. One can make the decision as whether to purchase a ship, insure the ship to minimize risk, or simply wait for a better opportunity. Furthermore this analysis can be used by ship manufacturers or ship owners to make a feasibility cost study of potential routes in reducing the possibility of ship loss, either through reduction of the human factor by training personnel or refining the design of a new ship to increase its robustness in severe weather conditions.

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Appendix I: DATA USED FOR THE CONSTRUCTION OF RIGHTING ARM CURVES

Nomenclature

Disp = Ship Displacement in metric tons

Δ = Ship Displacement in kilograms.

Although they defined as above, MathCAD recognizes both Disp and Δ with units of mass.

Δ_{44} = Moment of inertia of the ship around the roll axis

A_{44} = Added mass moment of inertia of the hull around the roll axis

B_{44} = Roll damping Coefficient

C_{44}= Restoring force coefficient

N(φ) = cubic spline represents the righting arms versus angle of heeling for tumblehome (GM=1.5m)

Ξ(φ) = cubic spline represents the righting arms versus angle of heeling for wall-sided (GM=1.5m)

O(φ) = cubic spline represents the righting arms versus angle of heeling for flare angle (GM=1.5m)

Π(φ) = cubic spline represents the righting arms versus angle of heeling for tumblehome (GM=2.0m)

P(φ) = cubic spline represents the righting arms versus angle of heeling for wall-sided (GM=2.0m)

Σ(φ) = cubic spline represents the righting arms versus angle of heeling for flare angle (GM=2.0m)

Γ = A function has no meaning. It helps MathCAD to understand what to solve

Data for Medium GM=1.5m

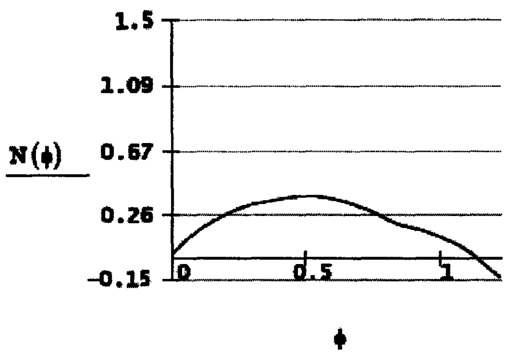
Tumblehome

$$x1 := \begin{pmatrix} 0 \\ 0.087 \\ 0.175 \\ 0.262 \\ 0.349 \\ 0.524 \\ 0.576 \\ 0.611 \\ 0.663 \\ 0.698 \\ 0.75 \\ 0.82 \\ 0.89 \\ 0.96 \\ 1.029 \\ 1.082 \\ 1.152 \\ 1.222 \end{pmatrix} \qquad y1 := \begin{pmatrix} 0 \\ 0.144 \\ 0.24 \\ 0.312 \\ 0.348 \\ 0.384 \\ 0.372 \\ 0.36 \\ 0.336 \\ 0.312 \\ 0.276 \\ 0.216 \\ 0.18 \\ 0.144 \\ 0.096 \\ 0.048 \\ -0.048 \\ -0.144 \end{pmatrix}$$

Tumblehome

$o := \mathrm{cspline}(x1, y1)$

$N(\phi) := \mathrm{interp}(o, x1, y1, \phi)$



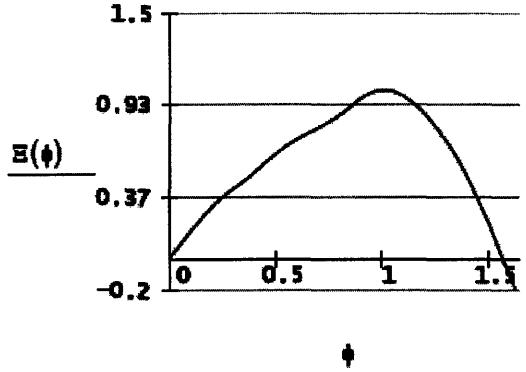
Wall Sided

$$x2 := \begin{pmatrix} 0 \\ 0.087 \\ 0.175 \\ 0.262 \\ 0.349 \\ 0.524 \\ 0.698 \\ 0.838 \\ 0.908 \\ 0.96 \\ 0.995 \\ 1.03 \\ 1.082 \\ 1.222 \\ 1.396 \\ 1.414 \\ 1.484 \\ 1.562 \\ 1.641 \end{pmatrix} \qquad y2 := \begin{pmatrix} 0 \\ 0.144 \\ 0.276 \\ 0.384 \\ 0.468 \\ 0.66 \\ 0.792 \\ 0.912 \\ 0.984 \\ 1.013 \\ 1.02 \\ 1.02 \\ 0.996 \\ 0.84 \\ 0.492 \\ 0.444 \\ 0.252 \\ 0 \\ -0.24 \end{pmatrix}$$

Wall Sided

$p := \text{cspline}(x2, y2)$

$\Xi(\phi) := \text{interp}(p, x2, y2, \phi)$



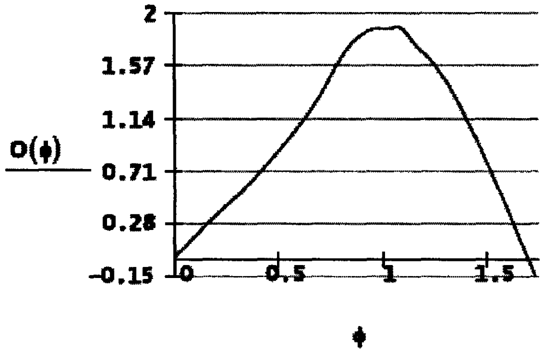
Flare

$$x3 := \begin{pmatrix} 0 \\ 0.087 \\ 0.175 \\ 0.262 \\ 0.349 \\ 0.524 \\ 0.698 \\ 0.82 \\ 0.89 \\ 0.925 \\ 0.96 \\ 0.995 \\ 1.03 \\ 1.082 \\ 1.152 \\ 1.222 \\ 1.309 \\ 1.484 \\ 1.658 \\ 1.745 \end{pmatrix} \qquad y3 := \begin{pmatrix} 0 \\ 0.144 \\ 0.3 \\ 0.444 \\ 0.588 \\ 0.924 \\ 1.32 \\ 1.68 \\ 1.812 \\ 1.848 \\ 1.872 \\ 1.874 \\ 1.872 \\ 1.884 \\ 1.752 \\ 1.632 \\ 1.428 \\ 0.84 \\ 0.144 \\ -0.216 \end{pmatrix}$$

Flare

$q := \mathrm{cspline}(x3, y3)$

$O(\phi) := \mathrm{interp}(q, x3, y3, \phi)$



Data for Large GM=2.0m

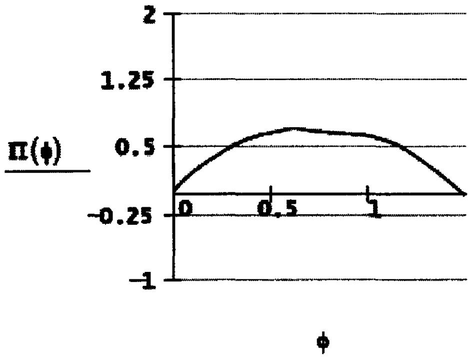
Tumblehome

$$x4 := \begin{pmatrix} 0 \\ 0.087 \\ 0.175 \\ 0.262 \\ 0.349 \\ 0.524 \\ 0.576 \\ 0.611 \\ 0.663 \\ 0.698 \\ 0.75 \\ 0.82 \\ 0.89 \\ 0.96 \\ 1.029 \\ 1.082 \\ 1.151 \\ 1.222 \\ 1.396 \\ 1.484 \end{pmatrix} \qquad y4 := \begin{pmatrix} 0 \\ 0.192 \\ 0.336 \\ 0.456 \\ 0.564 \\ 0.672 \\ 0.696 \\ 0.708 \\ 0.696 \\ 0.684 \\ 0.672 \\ 0.66 \\ 0.648 \\ 0.636 \\ 0.612 \\ 0.576 \\ 0.516 \\ 0.42 \\ 0.132 \\ -0.036 \end{pmatrix}$$

Tumblehome

$r := \text{cspline}(x4, y4)$

$\Pi(\phi) := \text{interp}(r, x4, y4, \phi)$



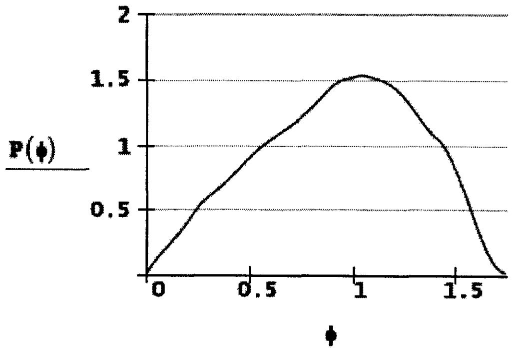
Wall Sided

$$x5 := \begin{pmatrix} 0 \\ 0.087 \\ 0.175 \\ 0.262 \\ 0.349 \\ 0.524 \\ 0.698 \\ 0.838 \\ 0.908 \\ 0.96 \\ 0.995 \\ 1.03 \\ 1.082 \\ 1.222 \\ 1.396 \\ 1.414 \\ 1.484 \\ 1.745 \end{pmatrix} \qquad y5 := \begin{pmatrix} 0 \\ 0.192 \\ 0.36 \\ 0.552 \\ 0.672 \\ 0.96 \\ 1.164 \\ 1.368 \\ 1.476 \\ 1.512 \\ 1.524 \\ 1.536 \\ 1.524 \\ 1.404 \\ 1.068 \\ 1.044 \\ 0.852 \\ 0.024 \end{pmatrix}$$

Wall Sided

$$s := \mathrm{cspline}(x5, y5)$$

$$P(\phi) := \mathrm{interp}(s, x5, y5, \phi)$$



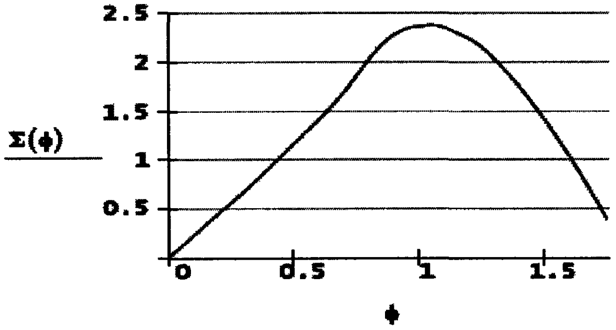
Flare

$$x6 := \begin{pmatrix} 0 \\ 0.087 \\ 0.175 \\ 0.262 \\ 0.349 \\ 0.524 \\ 0.698 \\ 0.82 \\ 0.89 \\ 0.925 \\ 0.96 \\ 0.995 \\ 1.03 \\ 1.082 \\ 1.152 \\ 1.222 \\ 1.309 \\ 1.484 \\ 1.658 \\ 1.745 \end{pmatrix} \qquad y6 := \begin{pmatrix} 0 \\ 0.192 \\ 0.396 \\ 0.588 \\ 0.792 \\ 1.236 \\ 1.704 \\ 2.112 \\ 2.28 \\ 2.328 \\ 2.364 \\ 2.376 \\ 2.388 \\ 2.376 \\ 2.304 \\ 2.208 \\ 2.004 \\ 1.452 \\ 0.756 \\ 0.36 \end{pmatrix}$$

Flare

$u := \mathrm{cspline}(x6, y6)$

$\Sigma(\phi) := \mathrm{interp}(u, x6, y6, \phi)$



Appendix II: CALCULATION OF THE INTEGRALS FOR ADDED MASS MOMENT OF INERTIA, A44 AND DAMPING COEFFICIENT, B44

Draft : $T := 8.413\mathrm{m}$

Sea Water Density : $\rho_{sw} := 1025 \dfrac{\mathrm{kg}}{\mathrm{m}^3}$

Ship Half-Beam
Along the Length:

$$B(x) := (0.173446 \cdot x)\cdot(0 < x \le 69.494) + 12.0548 \cdot (69.494 < x < 182.88)$$

Calculation of A44

$$A_{44} := 2 \cdot 0.05 T \cdot \rho_{sw} \cdot \mathrm{m}^4 \cdot \int_0^{182.88} B(x)^3 \, dx$$

$$A_{44} = 2.624 \times 10^7 \ \mathrm{kg} \cdot \mathrm{m}^2$$

Calculation of B44

$$B_{44} := 2 \cdot 0.04 T \cdot \rho_{sw} \cdot \sqrt{2g} \cdot \mathrm{m}^{\frac{7}{2}} \cdot \int_0^{182.88} B(x)^{\frac{5}{2}} \, dx$$

$$B_{44} = 3.06 \times 10^7 \ \frac{\mathrm{kg} \cdot \mathrm{m}^2}{\mathrm{s}}$$

Appendix III: MathCAD © CALCULATIONS

$L_R := 182.8800 \cdot m$ $B := 24.10968m$ $Draft := 8.413m$

$Disp := 14264ton$ $A_{wp} := 3571.4344 \cdot m^2$ $I_x := 152709.25 \cdot m^4$

$k_x := \frac{B}{3}$

For use with the differential equation for determining the dynamic roll angle

Note **: Unfortunately Mathcad does not allow units inside the differential equation solver, that 's way some formulas are divided by their unit to get a dimensionless number**

$\Delta_{44} := Disp \cdot k_x{}^2 \cdot \frac{1}{kg \cdot m^2}$

$A_{44} := \left(2.624 \times 10^7\right)$ $\boxed{\Delta_{44} + A_{44} = 8.62 \times 10^8}$

$B_{44} := \left(3.06 \times 10^7\right)$ $\boxed{B_{44} = 3.06 \times 10^7}$

$C_{44} := Disp \cdot g \cdot \frac{sec^2}{kg \cdot m}$ $\boxed{C_{44} = 1.269 \times 10^8}$

$L_m := 0.19m$ ***: length of the ship at the figure which used to define the heights of the hull above the waterline***

$\lambda := \frac{L_R}{L_m}$ ***: ratio of the length of the real ship over the ratio of the length of the ship in the figure***

The heights of the hull above the waterline for the ship of the figure

Long_Pos :=

	0
0	0
1	$3\cdot10^{-3}$
2	0.049
3	0.049
4	0.051
5	0.051
6	0.054
7	0.057
8	0.059
9	0.065
10	0.099
11	0.104
12	0.105
13	0.106
14	0.1125
15	0.1225
16	0.1295
17	0.1305
18	0.1375
19	0.148
20	0.1715
21	0.19

Height :=

	0
0	0
1	0.01
2	0.01
3	0.015
4	0.015
5	0.02
6	0.02
7	0.015
8	0.015
9	0.03
10	0.03
11	0.012
12	0.012
13	0.015
14	0.015
15	0.012
16	0.012
17	0.015
18	0.015
19	0.012
20	0.012
21	0

$Ls := Long\_Pos \cdot \lambda \cdot m$

$Hs := Height \cdot \lambda \cdot m$

The heights of the hull above the waterline for the real ship as estimated by multiplying with the ratio λ

Ls =

	0
0	0
1	2.888
2	47.164
3	47.164
4	49.089
5	49.089
6	51.976
7	54.864
8	56.789
9	62.564
10	95.29
11	100.103
12	101.065
13	102.028
14	108.284
15	117.909
16	124.647
17	125.61
18	132.347
19	142.454
20	165.073
21	182.88

m

Hs =

	0
0	0
1	9.625
2	9.625
3	14.438
4	14.438
5	19.251
6	19.251
7	14.438
8	14.438
9	28.876
10	28.876
11	11.55
12	11.55
13	14.438
14	14.438
15	11.55
16	11.55
17	14.438
18	14.438
19	11.55
20	11.55
21	0

m

$$\rho_{air} := 1.2\,\frac{kg}{m^3}$$

$$C_d := 1$$

$$j := 0 \,..\, 21$$

Area Calculation

$$f(j) := 0.5 \cdot (Hs_j + Hs_{j+1}) \cdot (Ls_{j+1} - Ls_j)$$

$$Area := \sum_{j=0}^{20} f(j) \qquad \boxed{Area = 2.689 \times 10^3\ m^2}$$

$$a(j) := 0.5 \cdot (Hs_j + Hs_{j+1}) \cdot (Ls_{j+1} - Ls_j) \cdot \frac{(Hs_j)^2 + Hs_j \cdot Hs_{j+1} + (Hs_{j+1})^2}{3(Hs_j + Hs_{j+1})}$$

$$M_x := \sum_{j=0}^{20} a(j) \qquad \boxed{M_x = 2.514 \times 10^7\ L}$$

$$Centroid_y := \frac{M_x}{Area} \qquad \boxed{Centroid_y = 9.35\ m}$$

Force Calculation

$$F_w(Va, \theta) := \frac{1}{2} \cdot \rho_{air} \cdot \left(0.5144\,\frac{m}{sec}\,Va \cdot \sin(\theta)\right)^2 \cdot C_d \cdot \sum_{j=0}^{20} f(j)$$

Moment Calculation

$$d(j) := f(j) \cdot \frac{1}{2} \cdot \left(\frac{Hs_j}{2} + \frac{Hs_{j+1}}{2} + Draft\right)$$

$$M(Va, \theta) := \frac{1}{2} \cdot \rho_{air} \cdot \left(0.5144 \cdot \frac{m}{sec}\,Va \cdot \sin(\theta)\right)^2 \cdot C_d \cdot \sum_{j=0}^{20} d(j)$$

Static Case Roll Angle

For Tumblehome Ship with GM=1.5 m

$$\Gamma_N(x) := M(V_a, \theta)\cdot\cos(x)^2 - \mathrm{Disp}\cdot g\cdot m\cdot N(x)$$

$$\mathrm{SOL}_N := \frac{180}{\pi}\cdot\mathrm{root}(\Gamma_N(x), x, 0, \pi)$$

For Wall Sided Ship with GM=1.5 m

$$\Gamma_\Xi(x) := M(V_a, \theta)\cdot\cos(x)^2 - \mathrm{Disp}\cdot g\cdot m\cdot \Xi(x)$$

$$\mathrm{SOL}_\Xi := \frac{180}{\pi}\cdot\mathrm{root}(\Gamma_\Xi(x), x, 0, \pi)$$

For Flare Sided Ship with GM=1.5 m

$$\Gamma_O(x) := M(V_a, \theta)\cdot\cos(x)^2 - \mathrm{Disp}\cdot g\cdot m\cdot O(x)$$

$$\mathrm{SOL}_O := \frac{180}{\pi}\cdot\mathrm{root}(\Gamma_O(x), x, 0, \pi)$$

For Tumblehome Ship with GM=2.0 m

$$\Gamma_{\Pi}(x) := M(V_a, \theta)\cdot\cos(x)^2 - Disp\cdot g\cdot m\cdot\Pi(x)$$

$$SOL_{\Pi} := \frac{180}{\pi}\cdot root\left(\Gamma_{\Pi}(x), x, 0, \frac{\pi}{3}\right)$$

For Wall Sided Ship with GM=2.0 m

$$\Gamma_{P}(x) := M(V_a, \theta)\cdot\cos(x)^2 - Disp\cdot g\cdot m\cdot P(x)$$

$$SOL_{P} := \frac{180}{\pi}\cdot root\left(\Gamma_{P}(x), x, 0, \frac{\pi}{3}\right)$$

For Flare Sided Ship with GM=2.0 m

$$\Gamma_{\Sigma}(x) := M(V_a, \theta)\cdot\cos(x)^2 - Disp\cdot g\cdot m\cdot\Sigma(x)$$

$$SOL_{\Sigma} := \frac{180}{\pi}\cdot root\left(\Gamma_{\Sigma}(x), x, 0, \frac{\pi}{3}\right)$$

Dynamic Case Roll Angle

$\Delta_{44} + A_{44} = 8.62 \times 10^{8}$

$B_{44} = 3.06 \times 10^{7}$

$C_{44} = 1.269 \times 10^{8}$

$D := M(V_a, \theta)\frac{1}{J}$

For Tumblehome Ship with GM=1.5 m

Given

$$(\Delta_{44} + A_{44})\cdot\frac{d^2}{dt^2}\phi(t) + B_{44}\cdot\frac{d}{dt}\phi(t) + C_{44}\cdot N(\phi(t)) = D\cdot\cos(\phi(t))^2$$

$\phi(0) = 0$ $\phi'(0) = 0$

$\phi1 := \text{Odesolve}(t, 200)$

For Tumblehome Ship with GM=2.0 m

Given

$$(\Delta_{44} + A_{44})\cdot\frac{d^2}{dt^2}\phi(t) + B_{44}\cdot\frac{d}{dt}\phi(t) + C_{44}\cdot \Pi(\phi(t)) = D\cdot\cos(\phi(t))^2$$

$\phi(0) = 0$ $\phi'(0) = 0$

$\phi2 := \text{Odesolve}(t, 200)$

For Wall Sided Ship with GM=1.5 m

Given

$$\left(\Delta_{44} + A_{44}\right)\cdot\frac{d^2}{dt^2}\phi(t) + B_{44}\cdot\frac{d}{dt}\phi(t) + C_{44}\cdot\Xi\left(\phi(t)\right) = D\cdot\cos\left(\phi(t)\right)^2$$

$\phi(0) = 0$ $\qquad\qquad$ $\phi'(0) = 0$

$\phi 3 := \mathrm{Odesolve}(t, 200)$

For Wall Sided Ship with GM=2.0 m

Given

$$\left(\Delta_{44} + A_{44}\right)\cdot\frac{d^2}{dt^2}\phi(t) + B_{44}\cdot\frac{d}{dt}\phi(t) + C_{44}\cdot P\left(\phi(t)\right) = D\cdot\cos\left(\phi(t)\right)^2$$

$\phi(0) = 0$ $\qquad\qquad$ $\phi'(0) = 0$

$\phi 4 := \mathrm{Odesolve}(t, 200)$

For Flare Sided Ship with GM=1.5 m

Given

$$\left(\Delta_{44} + A_{44}\right)\cdot\frac{d^2}{dt^2}\phi(t) + B_{44}\cdot\frac{d}{dt}\phi(t) + C_{44}\cdot O\left(\phi(t)\right) = D\cdot\cos\left(\phi(t)\right)^2$$

$\phi(0) = 0$ $\qquad\qquad$ $\phi'(0) = 0$

$\phi 5 := \mathrm{Odesolve}(t, 200)$

For Flare Sided Ship with GM=2.0 m

Given

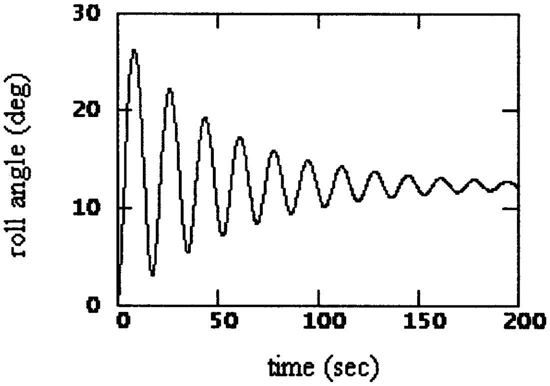
$$\left(\Delta_{44} + A_{44}\right)\cdot\frac{d^2}{dt^2}\phi(t) + B_{44}\cdot\frac{d}{dt}\phi(t) + C_{44}\cdot\Sigma\left(\phi(t)\right) = D\cdot\cos\left(\phi(t)\right)^2$$

$\phi(0) = 0$ $\qquad\qquad$ $\phi'(0) = 0$

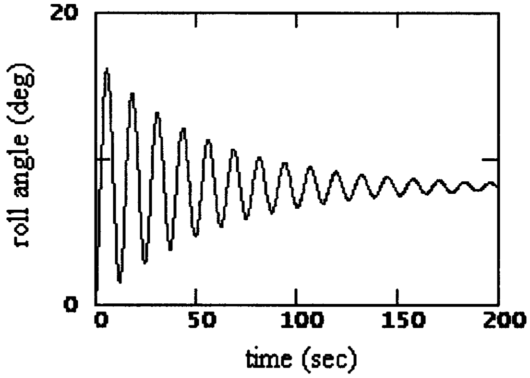
$\phi 6 := \mathrm{Odesolve}(t, 200)$

Samples of MathCAD runs

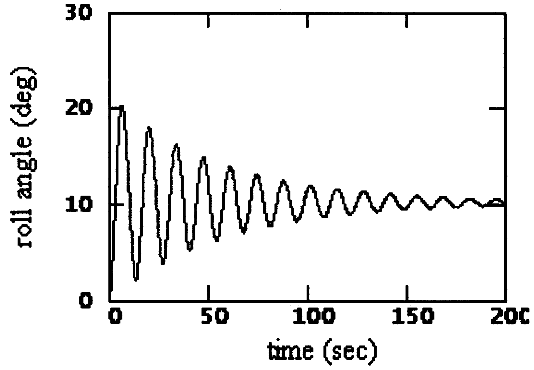
(wind speeds V_a=80 knots for different hull forms and different initial metacentric heights)



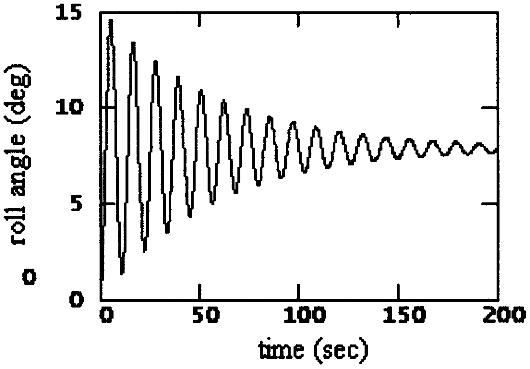
Tumblehome GM=1.5m



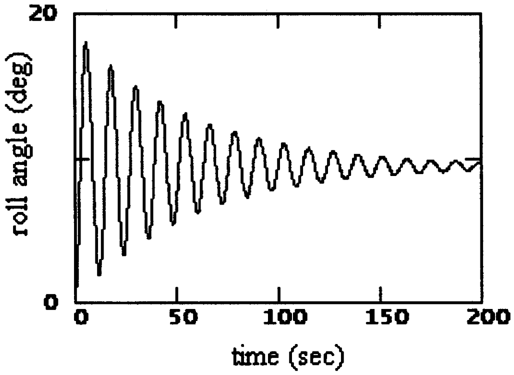
Tumblehome GM=2.0m



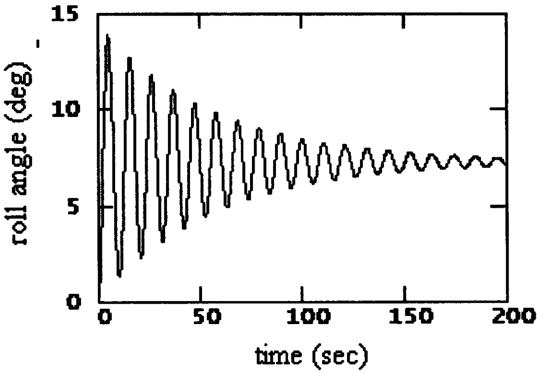
Wall- Sided GM=1.5m



Wall- Sided GM=2.0m

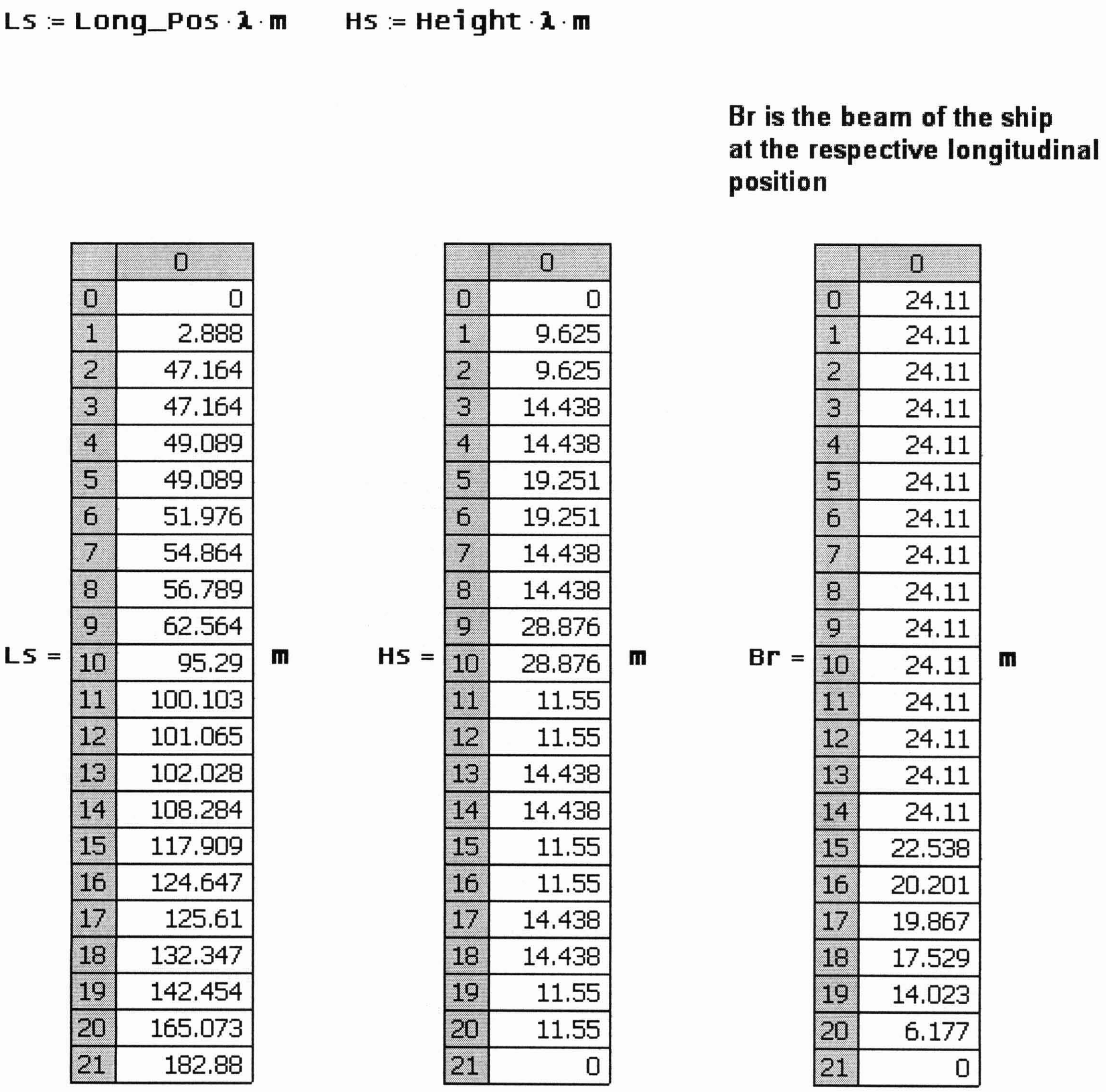


Flare-Sided GM=1.5m



Flare-Sided GM=2.0m

Enhanced MathCAD code to calculate the roll angles under the effect of the rising of the wateline as the ship heels



Ls := Long_Pos·1·m   Hs := Height·1·m

Br is the beam of the ship at the respective longitudinal position

Ls =

	0
0	0
1	2.888
2	47.164
3	47.164
4	49.089
5	49.089
6	51.976
7	54.864
8	56.789
9	62.564
10	95.29
11	100.103
12	101.065
13	102.028
14	108.284
15	117.909
16	124.647
17	125.61
18	132.347
19	142.454
20	165.073
21	182.88

m

Hs =

	0
0	0
1	9.625
2	9.625
3	14.438
4	14.438
5	19.251
6	19.251
7	14.438
8	14.438
9	28.876
10	28.876
11	11.55
12	11.55
13	14.438
14	14.438
15	11.55
16	11.55
17	14.438
18	14.438
19	11.55
20	11.55
21	0

m

Br =

	0
0	24.11
1	24.11
2	24.11
3	24.11
4	24.11
5	24.11
6	24.11
7	24.11
8	24.11
9	24.11
10	24.11
11	24.11
12	24.11
13	24.11
14	24.11
15	22.538
16	20.201
17	19.867
18	17.529
19	14.023
20	6.177
21	0

m

$$\rho_{air} := 1.2 \, \frac{kg}{m^3}$$

$$C_d := 1$$

$$j := 0 \,..\, 21$$

Area Calculation

$$f1(j, \phi) := 0.5 \cdot \left(Hs_j \cdot \cos(\phi) + \frac{Br_j \cdot \sin(\phi)}{2} + Hs_{j+1} \cdot \cos(\phi) + \frac{Br_{j+1} \cdot \sin(\phi)}{2} \right) \cdot \left(Ls_{j+1} - Ls_j \right)$$

Force Calculation

$$F1(Va, \theta, \phi) := \frac{1}{2} \cdot \rho_{air} \cdot \left(0.5144 \, \frac{m}{sec} Va \cdot \sin(\theta) \right)^2 \cdot C_d \cdot \sum_{j=0}^{20} f1(j, \phi)$$

Moment Calculation

$$d1(j, \phi) := f1(j, \phi) \cdot \frac{1}{2} \cdot \left(\frac{Hs_j}{2} \cdot \cos(\phi) + \frac{Br_j \cdot \sin(\phi)}{4} + \frac{Hs_{j+1}}{2} \cdot \cos(\phi) + \frac{Br_{j+1} \cdot \sin(\phi)}{4} + Draft \cdot \cos(\phi) \right)$$

$$M1(Va, \theta, \phi) := \frac{1}{2} \cdot \rho_{air} \cdot \left(0.5144 \cdot \frac{m}{sec} Va \cdot \sin(\theta) \right)^2 \cdot C_d \cdot \sum_{j=0}^{20} d1(j, \phi)$$

$$D1(\phi) := M1(V_a, \theta, \phi) \frac{1}{J}$$

For given wind speed and Va and wind direction θ in respect to the ship, D1 is function of φ only

For Tumblehome Ship with GM=1.5 m

Given

$$\left(\Delta_{44}+A_{44}\right)\cdot\frac{d^{2}}{dt^{2}}\phi(t)+B_{44}\cdot\frac{d}{dt}\phi(t)+C_{44}\cdot N(\phi(t))=D1(\phi(t))$$

$\phi(0)=0$ $\phi'(0)=0$

$\phi1 := \mathrm{Odesolve}(t, 200)$

For Tumblehome Ship with GM=2.0 m

Given

$$\left(\Delta_{44}+A_{44}\right)\cdot\frac{d^{2}}{dt^{2}}\phi(t)+B_{44}\cdot\frac{d}{dt}\phi(t)+C_{44}\cdot \Pi(\phi(t))=D1(\phi(t))$$

$\phi(0)=0$ $\phi'(0)=0$

$\phi2 := \mathrm{Odesolve}(t, 200)$

For Wall Sided Ship with GM=1.5 m

Given

$$\left(\Delta_{44}+A_{44}\right)\cdot\frac{d^2}{dt^2}\phi(t)+B_{44}\cdot\frac{d}{dt}\phi(t)+C_{44}\cdot\Xi\left(\phi(t)\right)=D1\left(\phi(t)\right)$$

$\phi(0)=0$ $\phi'(0)=0$

$\phi3 := \mathrm{Odesolve}(t, 200)$

For Wall Sided Ship with GM=2.0 m

Given

$$\left(\Delta_{44}+A_{44}\right)\cdot\frac{d^2}{dt^2}\phi(t)+B_{44}\cdot\frac{d}{dt}\phi(t)+C_{44}\cdot P\left(\phi(t)\right)=D1\left(\phi(t)\right)$$

$\phi(0)=0$ $\phi'(0)=0$

$\phi4 := \mathrm{Odesolve}(t, 200)$

For Flare Sided Ship with GM=1.5 m

Given

$$\left(\Delta_{44} + A_{44}\right)\cdot\frac{d^2}{dt^2}\phi(t) + B_{44}\cdot\frac{d}{dt}\phi(t) + C_{44}\cdot O\left(\phi(t)\right) = D1\left(\phi(t)\right)$$

$\phi(0) = 0$ $\qquad\qquad$ $\phi'(0) = 0$

$\phi5 := \mathrm{Odesolve}\ (t, 200)$

For Flare Sided Ship with GM=2.0 m

Given

$$\left(\Delta_{44} + A_{44}\right)\cdot\frac{d^2}{dt^2}\phi(t) + B_{44}\cdot\frac{d}{dt}\phi(t) + C_{44}\cdot \Sigma\left(\phi(t)\right) = D1\left(\phi(t)\right)$$

$\phi(0) = 0$ $\qquad\qquad$ $\phi'(0) = 0$

$\phi6 := \mathrm{Odesolve}\ (t, 200)$

Appendix IV: MATLAB© CODE

CODE: Rollangle

```
function rollangle(ship_x, ship_y)

%rollangle is the function that is going to be calculated
%To change time step size, duration of run (sec),
%For Changes in the number of time steps and initial conditions go to the function rk4.
%To change interpolation and/or equationfor d^2\phi _ dt^2 go to the function acceleration

%Parameters

%r_air is the density of the air
%cd is the drag coefficient

r_air = 1.2;
cd = 1;

%b_a is the quotient of the damping coefficient (B44) with the sum of the moment of inertia and
added moment of inertia (D44+A44)
b_a = 3.06/86.2;
%g_a is the quotient of restoring force coefficient (C44) with the sum of the moment of inertia and
added moment of inertia (D44+A44)
g_a = 1.269/8.62;

%M_f is the function that gives the moment applied on the hull by the wind as a function of wind
speed and wind direction relative to the ship
M_f = inline('0.5*r_air*(0.5144*va*sin(theta))^2*cd*3.623*10^4','r_air', 'cd', 'va', 'theta');

%Wind angles relative to the ship
theta_all = [1/6, 0.25, 1/3, 0.5]*pi;
%Wind speed [starting value]:interval:[ending value]
va_all = 50:2:100;


for a = 1: length(theta_all)

  for b = 1:length(va_all)

    theta = theta_all(a);

    va = va_all(b);

    M_a = M_f(r_air, cd, va, theta)/8.62*10^(-8);

    [x_max(a,b), x_stat(a,b)] = rk4(b_a, g_a, ship_x, ship_y, M_a);

    pack

  end

end
```

```
%Plotting
%Max angle
figure(2)
hold on
grid on
plot(va_all, x_max(1, :), va_all, x_max(2,:), va_all, x_max(3,:),va_all, x_max(4,:) )
legend('\theta = \pi/6', '\theta = \pi/4','\theta = \pi/3', '\theta = \pi/2')
xlabel('va'); ylabel('|\phi|_{dyn, max}')

%Static angle
figure(3)
hold on
grid on
plot(va_all, x_stat(1, :), va_all, x_stat(2,:), va_all, x_stat(3,:),va_all, x_stat(4,:) )
legend('\theta = \pi/6', '\theta = \pi/4','\theta = \pi/3', '\theta = \pi/2')
xlabel('va'); ylabel('\phi_{static}')
```

CODE: rk4

```
function [x_max, x_stat] = rk4(b_a, g_a, ship_x, ship_y, M_a)


%This function is used to integrate a 2nd order ode

%INPUT

%Time step size
k = 0.1;

%Duration of run (sec)
N_d = 200;

%Number of time steps
Nt = ceil(N_d/k);

%Initial conditions
x  = 0;

x_t= 0;

%for the run of non-zero initial conditions one has to assign values
%for x,x_t



%.....................................................................
%Time integration

for i =1:Nt

   %Assign values from previous time step
   x1 = x;

   x_t1 = x_t;

   x_tt1 = acceleration(b_a, g_a, ship_x, ship_y, M_a, x1, x_t1);

   %First  step
   x1_4= x1 + x_t1*0.5*k;

   x_t1_4 = x_t1 + x_tt1*0.5*k;

   x_tt1_4 = acceleration(b_a, g_a, ship_x, ship_y, M_a, x1_4, x_t1_4);

   %Second step
   x1_2= x1 + x_t1_4*0.5*k;

   x_t1_2 = x_t1 + x_tt1_4*0.5*k;
```

```
    x_tt1_2 = acceleration(b_a, g_a, ship_x, ship_y, M_a, x1_2, x_t1_2);


    %Third step
    x3_4= x1 + x_t1_2*k;

    x_t3_4 = x_t1 + x_tt1_2*k;

    x_tt3_4 = acceleration(b_a, g_a, ship_x, ship_y, M_a, x3_4, x_t3_4);


    %Fourth step
    x = x1 + (x_t1+ 2*x_t1_4 + 2*x_t1_2 + x_t3_4)*k/6;

    x_t = x_t1 + (x_tt1+ 2*x_tt1_4+ 2*x_tt1_2 + x_tt3_4)*k/6;

    x_rk4(i) = x;
    x_t_rk4(i)= x_t;

end

%Save results
x_max = 180/pi*max(abs(x_rk4));

x_stat = 180/pi*mean(x_rk4(Nt-100:Nt));

% pause
% figure(1)
% plot(1:Nt, x_rk4, 1:Nt, x_t_rk4)
% legend('x' ,'dx_{dt}')
% xlabel('time step')
% ylabel('position')
%
% hold off
```

CODE: Acceleration

```
function x_tt = acceleration(b_a, g_a, ship_x, ship_y, M_a, x, x_t);

%Interpolation for ship data
d = interp1( ship_x, ship_y, x, 'spline');

%Equation for acceleration of angle
x_tt = - b_a*x_t - g_a*d + M_a*(cos(x))^2;
```

Appendix V: TABLES OF ROLL ANGLES FOR ALL CASES WHEN INITIAL CONDITIONS ARE ZERO

Tumblehome for GM=1.5m									
V_Knots	**Static**				**V_Knots**	**Dynamic**			
θ	**30**	**45**	**60**	**90**	**θ**	**30**	**45**	**60**	**90**
50	0.81	1.68	2.62	3.72	**50**	1.55	3.28	5.20	7.34
52	0.88	1.84	2.86	4.04	**52**	1.69	3.58	5.70	8.09
54	0.95	2.01	3.15	4.39	**54**	1.83	3.89	6.24	8.89
56	1.03	2.18	3.46	4.86	**56**	1.98	4.23	6.81	9.75
58	1.10	2.35	3.76	5.37	**58**	2.13	4.58	7.42	10.66
60	1.18	2.52	4.03	5.80	**60**	2.29	4.96	8.07	11.63
62	1.26	2.69	4.33	6.22	**62**	2.46	5.35	8.76	12.66
64	1.35	2.90	4.72	6.78	**64**	2.63	5.77	9.50	13.74
66	1.44	3.13	5.16	7.47	**66**	2.82	6.21	10.27	14.90
68	1.54	3.38	5.58	8.16	**68**	3.01	6.67	11.09	16.15
70	1.64	3.64	5.93	8.77	**70**	3.20	7.16	11.94	17.51
72	1.75	3.87	6.31	9.33	**72**	3.41	7.67	12.84	19.00
74	1.87	4.09	6.81	9.93	**74**	3.63	8.21	13.79	20.62
76	1.98	4.34	7.41	10.63	**76**	3.85	8.78	14.79	22.37
78	2.10	4.65	8.01	11.54	**78**	4.08	9.38	15.86	24.23
80	2.22	5.01	8.56	12.54	**80**	4.33	10.00	17.01	26.21
82	2.34	5.37	9.05	13.05	**82**	4.58	10.65	18.25	28.32
84	2.46	5.68	9.54	14.01	**84**	4.84	11.33	19.59	30.63
86	2.59	5.96	10.08	15.17	**86**	5.11	12.04	21.03	33.23
88	2.72	6.27	10.71	16.16	**88**	5.40	12.78	22.56	36.30
90	2.86	6.66	11.51	17.85	**90**	5.69	13.54	24.18	40.17
92	3.02	7.14	12.40	**Capsize**	**92**	6.00	14.34	25.88	**Capsize**
94	3.19	7.64	12.95	**Capsize**	**94**	6.31	15.19	27.68	**Capsize**
96	3.37	8.12	13.41	**Capsize**	**96**	6.64	16.07	29.60	**Capsize**
98	3.55	8.56	14.76	**Capsize**	**98**	6.98	17.02	31.71	**Capsize**
100	3.72	8.97	15.19	**Capsize**	**100**	7.34	18.02	34.10	**Capsize**

Tumblehome for GM=2m									
V_Knots	**Static**				**V_Knots**	**Dynamic**			
θ	**30**	**45**	**60**	**90**	**θ**	**30**	**45**	**60**	**90**
50	0.64	1.31	2.00	2.74	**50**	1.23	2.53	3.90	5.35
52	0.69	1.42	2.18	2.98	**52**	1.33	2.75	4.25	5.85
54	0.75	1.53	2.37	3.23	**54**	1.44	2.98	4.62	6.37
56	0.81	1.65	2.56	3.50	**56**	1.55	3.22	5.00	6.92
58	0.87	1.78	2.77	3.78	**58**	1.67	3.47	5.41	7.50
60	0.93	1.91	2.98	4.10	**60**	1.79	3.73	5.84	8.11
62	1.00	2.05	3.20	4.43	**62**	1.92	4.01	6.29	8.76
64	1.06	2.20	3.42	4.78	**64**	2.05	4.30	6.76	9.44
66	1.13	2.36	3.66	5.12	**66**	2.19	4.60	7.25	10.15
68	1.20	2.52	3.92	5.46	**68**	2.33	4.91	7.77	10.90
70	1.28	2.68	4.20	5.82	**70**	2.47	5.24	8.31	11.68
72	1.36	2.85	4.49	6.23	**72**	2.63	5.58	8.87	12.49
74	1.44	3.02	4.79	6.69	**74**	2.78	5.93	9.47	13.34
76	1.52	3.20	5.09	7.17	**76**	2.95	6.30	10.08	14.22
78	1.60	3.38	5.38	7.65	**78**	3.11	6.68	10.72	15.13
80	1.69	3.58	5.69	8.11	**80**	3.29	7.08	11.39	16.07
82	1.78	3.78	6.02	8.57	**82**	3.47	7.49	12.09	17.04
84	1.87	4.00	6.40	9.04	**84**	3.65	7.92	12.81	18.03
86	1.97	4.23	6.80	9.55	**86**	3.84	8.37	13.55	19.05
88	2.07	4.47	7.22	10.09	**88**	4.04	8.83	14.32	20.10
90	2.17	4.72	7.64	10.67	**90**	4.24	9.31	15.11	21.19
92	2.28	4.96	8.04	11.27	**92**	4.45	9.81	15.92	22.32
94	2.39	5.20	8.43	11.88	**94**	4.67	10.32	16.75	23.50
96	2.51	5.44	8.84	12.50	**96**	4.89	10.85	17.60	24.74
98	2.62	5.69	9.26	13.12	**98**	5.12	11.40	18.47	26.03
100	2.74	5.96	9.71	13.75	**100**	5.35	11.96	19.36	27.39

Wall Sided for GM=1.5m

V_Knots	Static				V_Knots	Dynamic			
θ	30	45	60	90	θ	30	45	60	90
50	0.96	1.93	2.90	3.86	50	1.81	3.65	5.51	7.39
52	1.04	2.09	3.13	4.18	52	1.96	3.95	5.96	8.01
54	1.12	2.25	3.38	4.51	54	2.12	4.26	6.44	8.66
56	1.21	2.42	3.64	4.85	56	2.28	4.59	6.94	9.34
58	1.30	2.60	3.90	5.21	58	2.45	4.93	7.46	10.05
60	1.39	2.78	4.17	5.58	60	2.62	5.28	8.00	10.79
62	1.48	2.97	4.46	5.96	62	2.80	5.65	8.56	11.56
64	1.58	3.17	4.75	6.37	64	2.98	6.02	9.14	12.36
66	1.68	3.37	5.05	6.80	66	3.17	6.42	9.75	13.20
68	1.78	3.57	5.37	7.25	68	3.37	6.82	10.38	14.08
70	1.89	3.79	5.70	7.72	70	3.57	7.24	11.03	14.99
72	2.00	4.01	6.03	8.22	72	3.78	7.67	11.70	15.95
74	2.11	4.23	6.39	8.73	74	4.00	8.12	12.40	16.95
76	2.23	4.46	6.76	9.26	76	4.22	8.58	13.12	18.00
78	2.35	4.70	7.14	9.79	78	4.45	9.05	13.88	19.09
80	2.47	4.95	7.55	10.31	80	4.68	9.54	14.66	20.22
82	2.60	5.20	7.97	10.82	82	4.93	10.04	15.47	21.38
84	2.73	5.46	8.41	11.32	84	5.17	10.56	16.32	22.55
86	2.86	5.73	8.86	11.84	86	5.43	11.10	17.20	23.74
88	2.99	6.01	9.32	12.42	88	5.69	11.65	18.11	24.94
90	3.13	6.30	9.78	13.10	90	5.96	12.22	19.06	26.14
92	3.27	6.59	10.23	13.88	92	6.23	12.80	20.03	27.34
94	3.41	6.90	10.67	14.69	94	6.51	13.40	21.03	28.55
96	3.56	7.22	11.10	15.47	96	6.80	14.02	22.05	29.77
98	3.71	7.55	11.54	16.22	98	7.09	14.66	23.07	31.00
100	3.86	7.89	12.00	17.00	100	7.39	15.32	24.10	32.25

Wall Sided for GM=2m

V_Knots	Static				V_Knots	Dynamic			
θ	30	45	60	90	θ	30	45	60	90
50	0.61	1.26	1.94	2.69	50	1.17	2.45	3.82	5.29
52	0.66	1.37	2.12	2.93	52	1.27	2.66	4.17	5.79
54	0.71	1.48	2.32	3.19	54	1.38	2.89	4.54	6.31
56	0.77	1.60	2.51	3.47	56	1.49	3.13	4.93	6.86
58	0.83	1.72	2.72	3.77	58	1.60	3.39	5.35	7.43
60	0.89	1.86	2.93	4.10	60	1.72	3.65	5.78	8.02
62	0.95	2.00	3.15	4.43	62	1.84	3.93	6.23	8.64
64	1.02	2.15	3.38	4.78	64	1.97	4.22	6.70	9.27
66	1.09	2.30	3.64	5.13	66	2.11	4.52	7.19	9.91
68	1.16	2.47	3.92	5.49	68	2.25	4.84	7.69	10.56
70	1.23	2.63	4.20	5.87	70	2.39	5.17	8.21	11.21
72	1.31	2.80	4.49	6.27	72	2.54	5.51	8.75	11.87
74	1.38	2.97	4.79	6.68	74	2.70	5.87	9.29	12.53
76	1.47	3.15	5.10	7.09	76	2.86	6.24	9.85	13.21
78	1.55	3.34	5.41	7.49	78	3.03	6.62	10.41	13.89
80	1.63	3.55	5.73	7.87	80	3.20	7.02	10.98	14.58
82	1.72	3.77	6.07	8.26	82	3.38	7.43	11.55	15.30
84	1.82	4.00	6.42	8.69	84	3.57	7.84	12.12	16.04
86	1.91	4.23	6.78	9.14	86	3.76	8.27	12.69	16.80
88	2.02	4.47	7.13	9.55	88	3.96	8.71	13.28	17.61
90	2.12	4.71	7.48	9.93	90	4.16	9.15	13.87	18.44
92	2.23	4.96	7.81	10.30	92	4.38	9.60	14.47	19.31
94	2.34	5.21	8.14	10.70	94	4.60	10.06	15.08	20.22
96	2.46	5.47	8.50	11.09	96	4.82	10.52	15.71	21.15
98	2.57	5.74	8.88	11.48	98	5.05	10.98	16.37	22.09
100	2.69	6.01	9.27	11.88	100	5.29	11.45	17.04	23.05

Flare Sided for GM=1.5m

V_Knots	Static				V_Knots	Dynamic			
θ	30	45	60	90	θ	30	45	60	90
50	1.05	2.06	3.05	3.97	50	1.98	3.86	5.66	7.41
52	1.13	2.23	3.28	4.26	52	2.14	4.16	6.09	7.97
54	1.22	2.40	3.52	4.56	54	2.30	4.46	6.54	8.55
56	1.31	2.57	3.76	4.87	56	2.47	4.78	7.00	9.16
58	1.40	2.75	4.01	5.19	58	2.64	5.11	7.47	9.78
60	1.49	2.93	4.26	5.52	60	2.82	5.45	7.96	10.42
62	1.59	3.12	4.52	5.87	62	3.00	5.79	8.46	11.08
64	1.69	3.31	4.78	6.22	64	3.19	6.15	8.98	11.77
66	1.80	3.50	5.06	6.58	66	3.38	6.51	9.51	12.47
68	1.91	3.70	5.34	6.96	68	3.58	6.89	10.06	13.20
70	2.02	3.90	5.63	7.34	70	3.79	7.27	10.62	13.95
72	2.14	4.10	5.93	7.73	72	3.99	7.66	11.20	14.72
74	2.25	4.31	6.23	8.13	74	4.21	8.07	11.80	15.51
76	2.37	4.52	6.55	8.54	76	4.42	8.48	12.41	16.32
78	2.50	4.74	6.87	8.96	78	4.65	8.90	13.04	17.15
80	2.62	4.96	7.20	9.39	80	4.87	9.33	13.68	17.99
82	2.75	5.19	7.54	9.83	82	5.11	9.77	14.34	18.85
84	2.88	5.42	7.88	10.28	84	5.34	10.22	15.01	19.71
86	3.01	5.66	8.23	10.75	86	5.58	10.69	15.70	20.59
88	3.14	5.90	8.59	11.22	88	5.83	11.16	16.40	21.48
90	3.28	6.15	8.95	11.71	90	6.08	11.64	17.12	22.37
92	3.41	6.41	9.32	12.21	92	6.34	12.14	17.85	23.26
94	3.55	6.67	9.70	12.71	94	6.60	12.64	18.59	24.16
96	3.69	6.93	10.09	13.24	96	6.86	13.16	19.34	25.05
98	3.83	7.20	10.48	13.77	98	7.13	13.68	20.10	25.95
100	3.97	7.48	10.89	14.33	100	7.41	14.22	20.86	26.85

Flare Sided for GM=2.0 m

V_Knots	Static				V_Knots	Dynamic			
θ	30	45	60	90	θ	30	45	60	90
50	0.78	1.55	2.29	3.01	50	1.49	2.92	4.31	5.68
52	0.85	1.67	2.47	3.24	52	1.61	3.15	4.65	6.11
54	0.91	1.80	2.65	3.47	54	1.73	3.39	5.00	6.57
56	0.98	1.93	2.84	3.72	56	1.86	3.63	5.36	7.04
58	1.05	2.06	3.03	3.98	58	1.99	3.89	5.73	7.52
60	1.12	2.20	3.23	4.24	60	2.12	4.15	6.11	8.02
62	1.20	2.34	3.44	4.51	62	2.26	4.42	6.50	8.53
64	1.28	2.49	3.65	4.79	64	2.41	4.69	6.90	9.06
66	1.36	2.64	3.87	5.08	66	2.56	4.98	7.32	9.61
68	1.44	2.79	4.09	5.37	68	2.71	5.27	7.74	10.17
70	1.52	2.95	4.32	5.67	70	2.87	5.57	8.18	10.74
72	1.61	3.11	4.56	5.98	72	3.03	5.87	8.63	11.34
74	1.69	3.27	4.80	6.29	74	3.19	6.19	9.09	11.94
76	1.78	3.44	5.05	6.62	76	3.36	6.51	9.56	12.57
78	1.87	3.62	5.30	6.95	78	3.53	6.84	10.04	13.21
80	1.97	3.79	5.56	7.28	80	3.71	7.17	10.53	13.87
82	2.06	3.97	5.83	7.63	82	3.89	7.52	11.04	14.53
84	2.16	4.16	6.10	7.98	84	4.07	7.87	11.56	15.22
86	2.26	4.35	6.37	8.34	86	4.26	8.23	12.09	15.91
88	2.36	4.54	6.65	8.70	88	4.45	8.59	12.64	16.62
90	2.46	4.74	6.94	9.08	90	4.64	8.97	13.19	17.34
92	2.57	4.94	7.23	9.46	92	4.84	9.35	13.76	18.06
94	2.67	5.14	7.52	9.85	94	5.05	9.74	14.33	18.79
96	2.78	5.35	7.83	10.25	96	5.25	10.13	14.92	19.53
98	2.89	5.56	8.13	10.66	98	5.46	10.54	15.52	20.28
100	3.01	5.78	8.45	11.08	100	5.68	10.95	16.13	21.02

Appendix VI: TABLES AND FIGURES OF ROLL ANGLES FOR ALL CASES WHEN INITIAL CONDITIONS ARE NON-ZERO

TUMBLEHOME

INITIAL ANGLE OF HEELING (6 degrees)

Tumblehome for GM=1.5m				
V_Knots	Dynamic			
	30	45	60	90
50	8.14	10.18	12.38	14.76
52	8.30	10.53	12.95	15.58
54	8.47	10.89	13.54	16.46
56	8.64	11.28	14.18	17.41
58	8.83	11.68	14.85	18.44
60	9.02	12.11	15.56	19.56
62	9.21	12.55	16.32	20.76
64	9.42	13.02	17.13	22.05
66	9.64	13.51	18.00	23.43
68	9.86	14.02	18.93	24.90
70	10.09	14.56	19.92	26.47
72	10.34	15.12	20.98	28.15
74	10.59	15.72	22.11	29.97
76	10.85	16.34	23.30	31.97
78	11.11	17.00	24.56	34.24
80	11.39	17.70	25.89	36.84
82	11.68	18.43	27.30	39.99
84	11.98	19.21	28.81	**Capsize**
86	12.29	20.03	30.43	**Capsize**
88	12.61	20.90	32.20	**Capsize**
90	12.93	21.81	34.17	**Capsize**
92	13.28	22.77	36.39	**Capsize**
94	13.63	23.77	38.97	**Capsize**
96	13.99	24.81	**Capsize**	**Capsize**
98	14.37	25.90	**Capsize**	**Capsize**
100	14.76	27.05	**Capsize**	**Capsize**

Tumblehome for GM=2.0m				
V_Knots	Dynamic			
	30	45	60	90
50	7.36	8.82	10.34	11.94
52	7.48	9.06	10.72	12.47
54	7.60	9.31	11.13	13.03
56	7.72	9.58	11.55	13.62
58	7.86	9.86	11.99	14.24
60	7.99	10.15	12.46	14.88
62	8.13	10.46	12.94	15.55
64	8.28	10.77	13.45	16.26
66	8.43	11.10	13.97	16.99
68	8.59	11.45	14.52	17.74
70	8.76	11.81	15.09	18.52
72	8.93	12.17	15.68	19.34
74	9.10	12.56	16.29	20.19
76	9.28	12.96	16.92	21.07
78	9.47	13.37	17.57	21.99
80	9.66	13.79	18.24	22.94
82	9.86	14.23	18.93	23.95
84	10.07	14.69	19.65	25.00
86	10.28	15.15	20.39	26.10
88	10.49	15.63	21.16	27.25
90	10.72	16.13	21.96	28.45
92	10.95	16.64	22.78	29.70
94	11.18	17.16	23.65	31.00
96	11.43	17.69	24.54	32.34
98	11.68	18.24	25.47	33.72
100	11.94	18.81	26.44	35.13

INITIAL ANGULAR VELOCITY (0.1 rad/sec)

Tumblehome for GM=1.5m				
V_Knots	Dynamic			
	30	45	60	90
50	12.69	14.05	15.58	17.34
52	12.80	14.28	15.99	17.96
54	12.91	14.54	16.43	18.65
56	13.02	14.80	16.90	19.39
58	13.14	15.09	17.41	20.20
60	13.27	15.39	17.95	21.08
62	13.40	15.70	18.54	22.04
64	13.54	16.04	19.17	23.07
66	13.68	16.40	19.85	24.18
68	13.83	16.78	20.59	25.38
70	13.99	17.19	21.37	26.67
72	14.15	17.62	22.21	28.07
74	14.32	18.07	23.12	29.59
76	14.50	18.56	24.08	31.26
78	14.69	19.07	25.10	33.15
80	14.88	19.62	26.20	35.29
82	15.08	20.20	27.36	37.80
84	15.29	20.81	28.62	40.93
86	15.52	21.46	29.97	**Capsize**
88	15.74	22.15	31.45	**Capsize**
90	15.98	22.88	33.09	**Capsize**
92	16.23	23.64	34.92	**Capsize**
94	16.49	24.45	37.01	**Capsize**
96	16.76	25.31	39.47	**Capsize**
98	17.04	26.20	**Capsize**	**Capsize**
100	17.34	27.15	**Capsize**	**Capsize**

Tumblehome for GM=2.0m				
V_Knots	Dynamic			
	30	45	60	90
50	10.59	11.49	12.47	13.54
52	10.66	11.65	12.73	13.90
54	10.74	11.81	12.99	14.29
56	10.81	11.98	13.28	14.71
58	10.89	12.16	13.58	15.14
60	10.98	12.35	13.90	15.61
62	11.07	12.55	14.23	16.10
64	11.16	12.76	14.58	16.61
66	11.25	12.98	14.95	17.16
68	11.35	13.21	15.35	17.74
70	11.45	13.45	15.75	18.34
72	11.56	13.70	16.19	18.97
74	11.67	13.96	16.64	19.64
76	11.79	14.24	17.11	20.34
78	11.90	14.53	17.60	21.07
80	12.03	14.83	18.12	21.85
82	12.16	15.14	18.66	22.67
84	12.29	15.46	19.22	23.53
86	12.43	15.80	19.80	24.44
88	12.57	16.16	20.42	25.39
90	12.72	16.52	21.05	26.40
92	12.87	16.90	21.72	27.46
94	13.03	17.29	22.42	28.57
96	13.19	17.70	23.15	29.73
98	13.36	18.12	23.92	30.94
100	13.54	18.56	24.72	32.20

WALL-SIDED

INITIAL ANGLE OF HEELING (6 degrees)

Wall Sided for GM=1.5m				
V_Knots	Dynamic			
	30	45	60	90
50	7.05	8.94	10.86	12.82
52	7.21	9.25	11.33	13.47
54	7.36	9.57	11.83	14.16
56	7.53	9.91	12.35	14.87
58	7.70	10.26	12.89	15.62
60	7.88	10.63	13.46	16.42
62	8.06	11.00	14.05	17.24
64	8.25	11.40	14.66	18.11
66	8.45	11.80	15.30	19.02
68	8.65	12.22	15.97	19.96
70	8.86	12.66	16.67	20.94
72	9.08	13.11	17.40	21.94
74	9.30	13.58	18.15	22.97
76	9.53	14.07	18.94	24.02
78	9.77	14.57	19.75	25.08
80	10.01	15.08	20.58	26.16
82	10.26	15.62	21.44	27.25
84	10.52	16.17	22.32	28.36
86	10.78	16.75	23.22	29.49
88	11.05	17.34	24.13	30.63
90	11.33	17.95	25.05	31.79
92	11.61	18.59	25.98	32.97
94	11.90	19.24	26.93	34.17
96	12.20	19.91	27.88	35.39
98	12.51	20.59	28.85	36.64
100	12.82	21.29	29.83	37.90

Wall Sided for GM=2.0m				
V_Knots	Dynamic			
	30	45	60	90
50	7.83	9.21	10.60	11.98
52	7.95	9.44	10.94	12.43
54	8.06	9.68	11.30	12.89
56	8.18	9.92	11.66	13.37
58	8.31	10.18	12.03	13.86
60	8.44	10.44	12.42	14.37
62	8.57	10.71	12.82	14.89
64	8.71	10.99	13.23	15.44
66	8.86	11.28	13.65	16.01
68	9.00	11.57	14.08	16.60
70	9.16	11.87	14.53	17.22
72	9.32	12.18	14.99	17.87
74	9.48	12.50	15.46	18.54
76	9.65	12.83	15.95	19.24
78	9.82	13.16	16.47	19.98
80	9.99	13.50	17.00	20.73
82	10.17	13.85	17.55	21.51
84	10.36	14.21	18.11	22.31
86	10.55	14.58	18.70	23.12
88	10.74	14.95	19.32	23.95
90	10.94	15.34	19.95	24.79
92	11.14	15.73	20.61	25.64
94	11.34	16.14	21.27	26.51
96	11.55	16.57	21.96	27.38
98	11.77	17.00	22.66	28.26
100	11.98	17.45	23.37	29.15

INITIAL ANGULAR VELOCITY(0.1 rad/sec)

Wall Sided for GM=1.5m				
V_Knots	Dynamic			
	30	45	60	90
50	12.11	13.21	14.41	15.72
52	12.20	13.40	14.72	16.17
54	12.29	13.60	15.05	16.65
56	12.38	13.81	15.40	17.16
58	12.48	14.03	15.77	17.71
60	12.58	14.26	16.16	18.29
62	12.69	14.51	16.58	18.91
64	12.80	14.76	17.01	19.56
66	12.92	15.03	17.48	20.24
68	13.04	15.32	17.96	20.96
70	13.16	15.61	18.48	21.71
72	13.30	15.92	19.02	22.50
74	13.43	16.25	19.58	23.31
76	13.57	16.59	20.18	24.15
78	13.72	16.94	20.80	25.02
80	13.87	17.32	21.44	25.91
82	14.03	17.70	22.11	26.83
84	14.19	18.11	22.80	27.76
86	14.36	18.53	23.51	28.72
88	14.54	18.98	24.24	29.70
90	14.72	19.44	25.00	30.71
92	14.90	19.91	25.76	31.74
94	15.10	20.41	26.55	32.79
96	15.30	20.92	27.36	33.87
98	15.51	21.45	28.18	34.97
100	15.72	21.99	29.02	36.09

Wall Sided for GM=2.0m				
V_Knots	Dynamic			
	30	45	60	90
50	10.44	11.24	12.10	12.99
52	10.50	11.38	12.31	13.28
54	10.57	11.53	12.54	13.59
56	10.64	11.68	12.77	13.93
58	10.71	11.83	13.02	14.27
60	10.79	11.99	13.28	14.64
62	10.87	12.16	13.54	15.02
64	10.95	12.34	13.83	15.42
66	11.04	12.52	14.12	15.84
68	11.12	12.71	14.43	16.29
70	11.21	12.91	14.75	16.76
72	11.31	13.12	15.09	17.25
74	11.41	13.33	15.44	17.77
76	11.51	13.55	15.80	18.32
78	11.61	13.78	16.18	18.89
80	11.72	14.02	16.59	19.50
82	11.83	14.27	17.00	20.13
84	11.94	14.52	17.44	20.79
86	12.06	14.79	17.90	21.48
88	12.18	15.06	18.38	22.19
90	12.31	15.34	18.88	22.91
92	12.44	15.64	19.40	23.66
94	12.57	15.94	19.94	24.42
96	12.70	16.26	20.51	25.20
98	12.84	16.59	21.09	25.99
100	12.99	16.93	21.69	26.79

FLARE-SIDED

INITIAL ANGLE OF HEELING (6 degrees)

Flare Sided for GM=1.5m				
V_Knots	Dynamic			
	30	45	60	90
50	6.48	8.34	10.15	11.94
52	6.64	8.64	10.59	12.52
54	6.79	8.95	11.05	13.13
56	6.96	9.27	11.52	13.75
58	7.13	9.60	12.01	14.40
60	7.31	9.94	12.51	15.06
62	7.49	10.29	13.03	15.75
64	7.67	10.65	13.57	16.46
66	7.87	11.02	14.12	17.19
68	8.06	11.41	14.69	17.93
70	8.26	11.80	15.28	18.69
72	8.47	12.21	15.88	19.47
74	8.69	12.62	16.49	20.26
76	8.91	13.05	17.12	21.07
78	9.13	13.48	17.76	21.88
80	9.36	13.93	18.42	22.71
82	9.59	14.39	19.08	23.54
84	9.83	14.86	19.76	24.38
86	10.08	15.34	20.45	25.23
88	10.33	15.83	21.15	26.07
90	10.58	16.33	21.86	26.93
92	10.84	16.84	22.57	27.79
94	11.11	17.36	23.29	28.65
96	11.38	17.89	24.02	29.52
98	11.66	18.42	24.75	30.39
100	11.94	18.96	25.48	31.26

Flare Sided for GM=2.0m				
V_Knots	Dynamic			
	30	45	60	90
50	6.19	7.60	8.99	10.36
52	6.30	7.83	9.33	10.81
54	6.43	8.07	9.68	11.27
56	6.55	8.31	10.04	11.75
58	6.68	8.56	10.41	12.25
60	6.81	8.83	10.80	12.76
62	6.95	9.09	11.20	13.29
64	7.09	9.37	11.61	13.83
66	7.24	9.66	12.04	14.39
68	7.39	9.95	12.47	14.96
70	7.54	10.25	12.92	15.55
72	7.70	10.56	13.38	16.16
74	7.87	10.88	13.86	16.78
76	8.03	11.21	14.34	17.40
78	8.21	11.55	14.83	18.04
80	8.38	11.89	15.34	18.69
82	8.56	12.24	15.86	19.35
84	8.75	12.60	16.39	20.02
86	8.93	12.97	16.92	20.70
88	9.13	13.35	17.47	21.39
90	9.32	13.73	18.03	22.09
92	9.52	14.12	18.59	22.79
94	9.72	14.52	19.16	23.49
96	9.93	14.93	19.73	24.21
98	10.14	15.34	20.32	24.93
100	10.36	15.77	20.91	25.66

INITIAL ANGULAR VELOCITY (0.1 rad/sec)

Flare Sided for GM=1.5m				
V_Knots	Dynamic			
	30	45	60	90
50	11.81	12.78	13.82	14.93
52	11.88	12.95	14.09	15.30
54	11.96	13.12	14.37	15.70
56	12.05	13.30	14.66	16.11
58	12.14	13.50	14.97	16.55
60	12.23	13.70	15.29	17.01
62	12.32	13.90	15.63	17.49
64	12.42	14.12	15.99	17.99
66	12.52	14.35	16.36	18.51
68	12.63	14.59	16.75	19.06
70	12.74	14.84	17.15	19.62
72	12.86	15.10	17.57	20.21
74	12.98	15.36	18.01	20.81
76	13.10	15.64	18.46	21.44
78	13.22	15.93	18.93	22.08
80	13.36	16.23	19.41	22.74
82	13.50	16.54	19.92	23.41
84	13.64	16.87	20.43	24.10
86	13.78	17.20	20.96	24.80
88	13.93	17.54	21.51	25.51
90	14.08	17.90	22.06	26.24
92	14.24	18.26	22.63	26.97
94	14.41	18.64	23.21	27.71
96	14.58	19.02	23.80	28.47
98	14.75	19.42	24.40	29.23
100	14.93	19.83	25.01	30.00

Flare Sided for GM=2.0m				
V_Knots	Dynamic			
	30	45	60	90
50	10.24	10.98	11.76	12.58
52	10.30	11.10	11.96	12.86
54	10.36	11.23	12.17	13.16
56	10.42	11.37	12.39	13.46
58	10.49	11.51	12.61	13.79
60	10.55	11.66	12.86	14.13
62	10.63	11.82	13.11	14.49
64	10.70	11.98	13.37	14.86
66	10.78	12.15	13.65	15.25
68	10.86	12.33	13.94	15.66
70	10.95	12.51	14.24	16.08
72	11.03	12.71	14.55	16.53
74	11.12	12.91	14.88	16.99
76	11.21	13.12	15.22	17.45
78	11.31	13.33	15.57	17.95
80	11.41	13.56	15.93	18.45
82	11.51	13.79	16.31	18.97
84	11.62	14.03	16.70	19.51
86	11.72	14.27	17.10	20.05
88	11.84	14.53	17.51	20.61
90	11.95	14.80	17.93	21.19
92	12.07	15.07	18.37	21.78
94	12.20	15.35	18.81	22.37
96	12.32	15.64	19.27	22.98
98	12.45	15.94	19.74	23.60
100	12.58	16.24	20.22	24.23

A. Results with initial angle of heeling

Tumblehome Hull Form

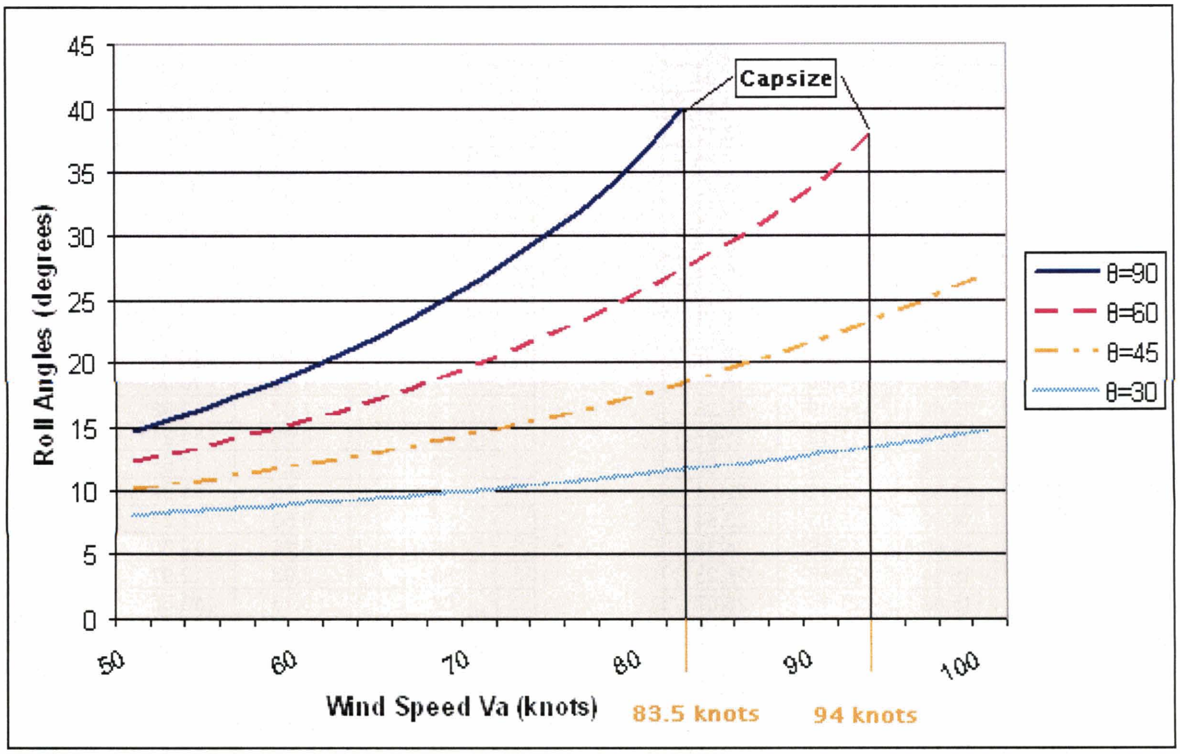


Figure 41: Maximum Roll Angles For Dynamic Case (Tumblehome GM=1.5m)

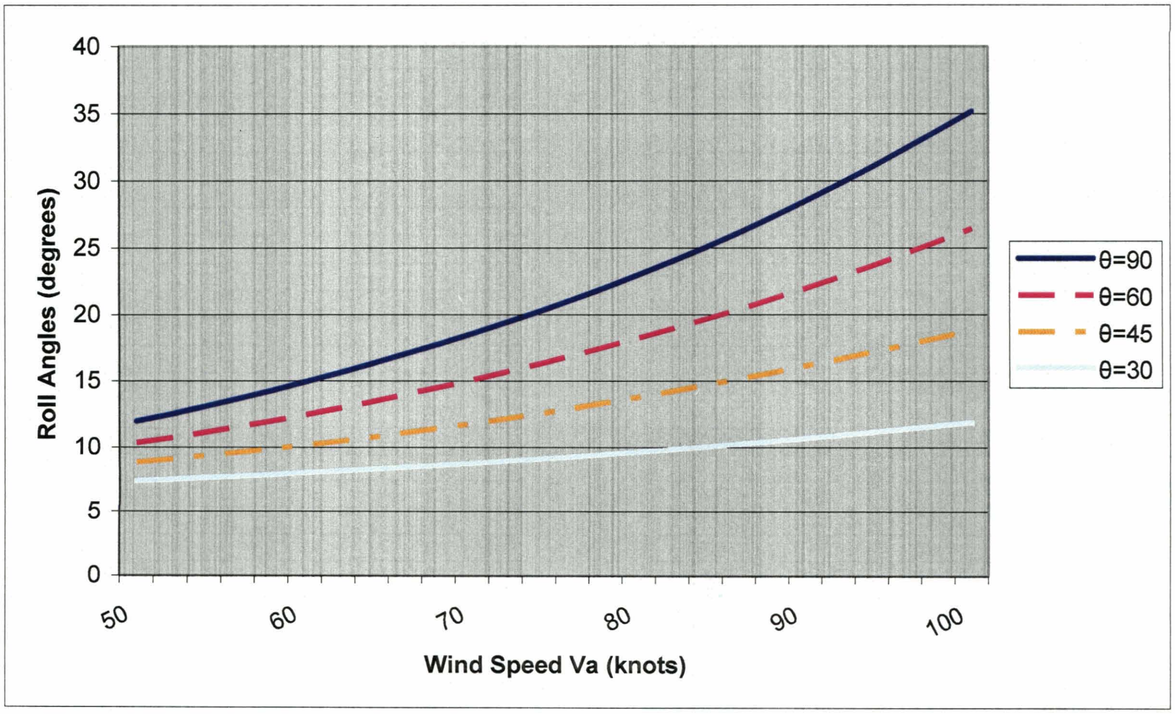


Figure 42: Maximum Roll Angles For Dynamic Case (Tumblehome GM=2.0m)

Wall Sided Hull Form

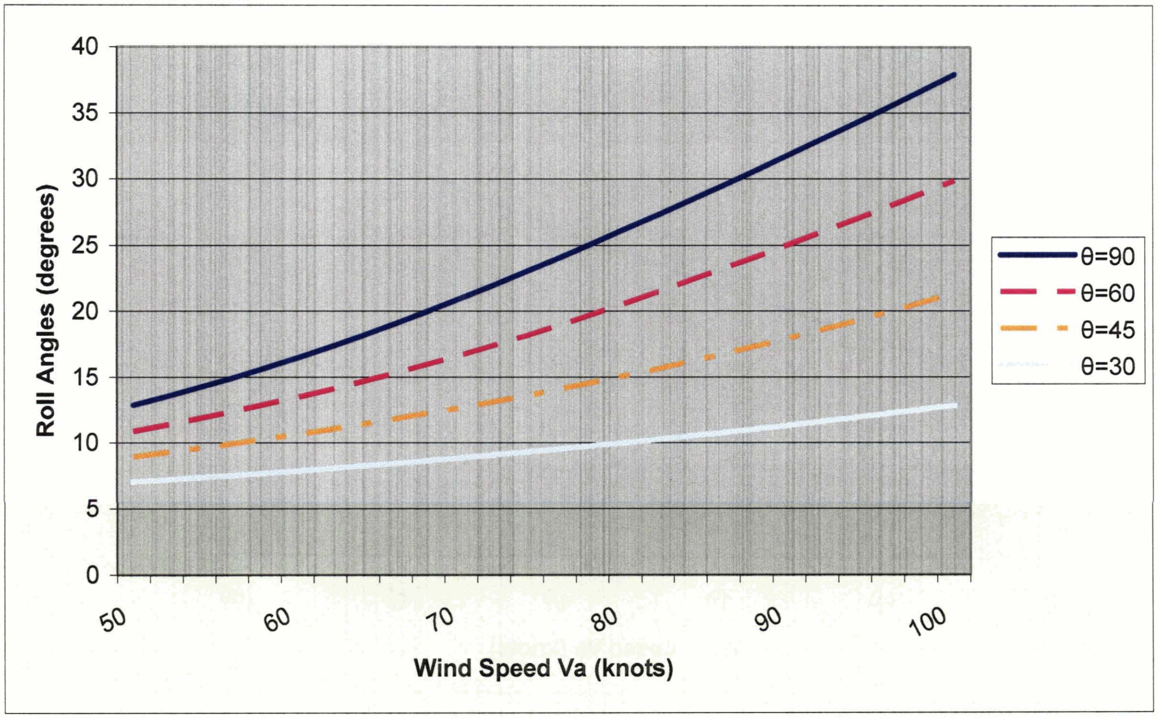


Figure 43: Maximum Roll Angles For Dynamic Case (Wall Sided GM=1.5m)

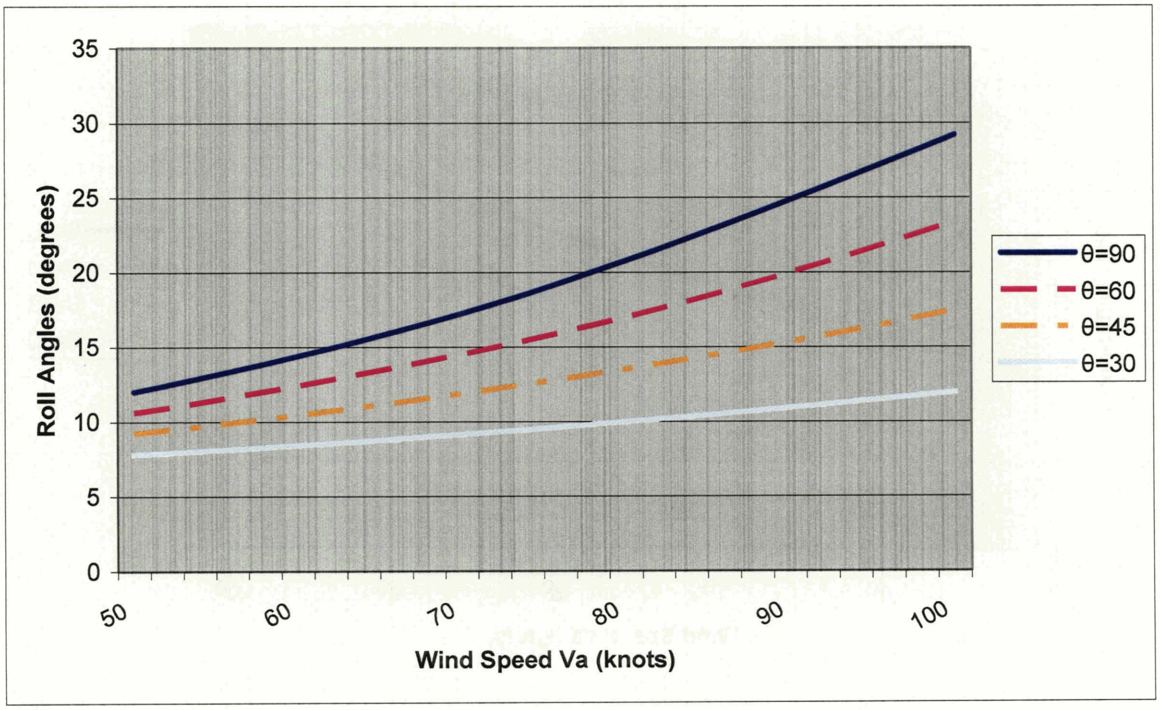


Figure 44: Maximum Roll Angles For Dynamic Case (Wall Sided GM=2.0m)

Flare-Sided Hull Form

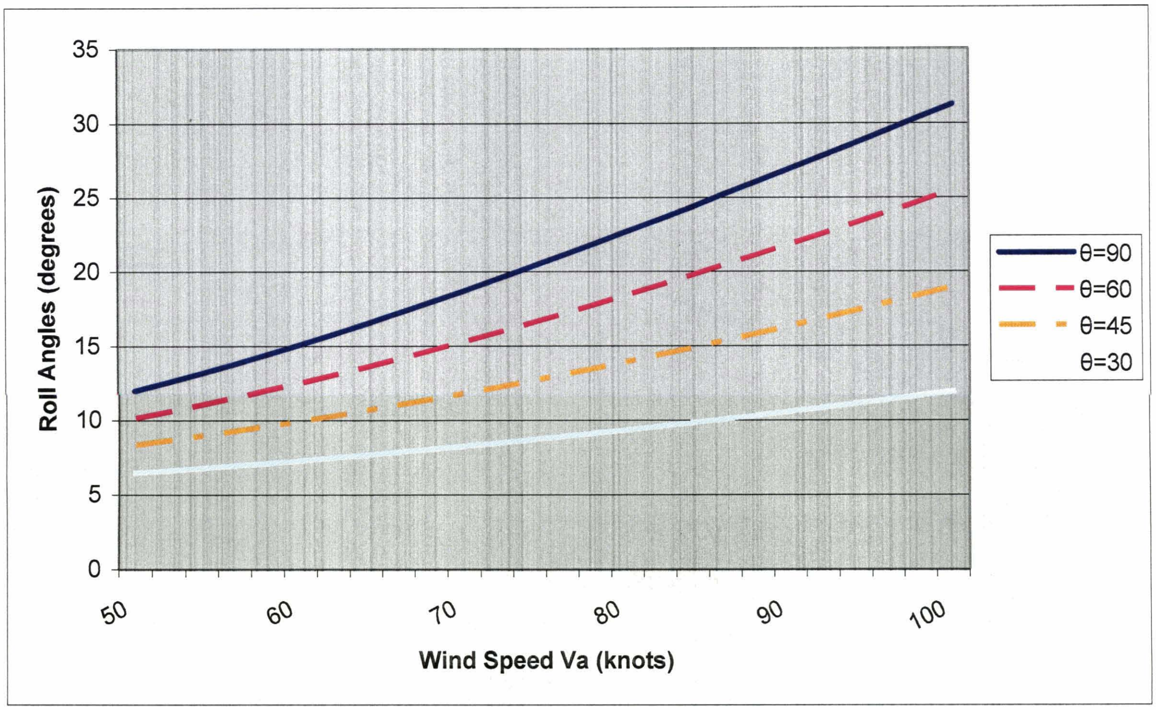


Figure 45: Maximum Roll Angles For Dynamic Case (Flare Sided GM=1.5m)

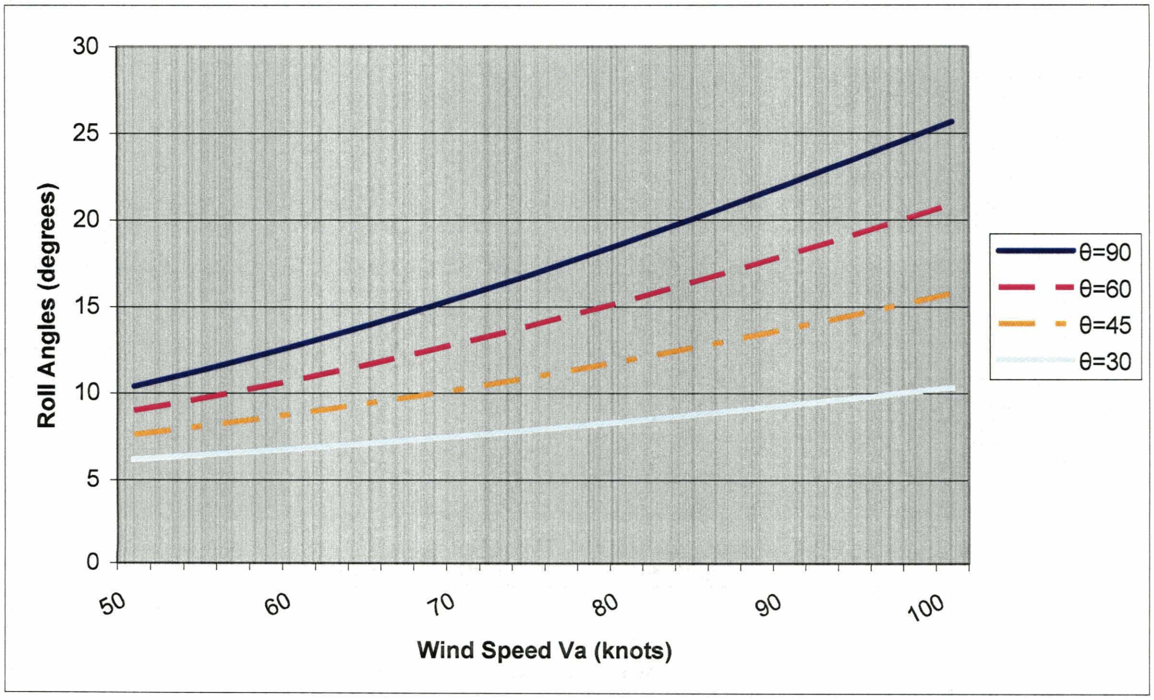


Figure 46: Maximum Roll Angles For Dynamic Case (Flare Sided GM=2.0m)

B. Results with initial angular velocity

Tumblehome Hull Form

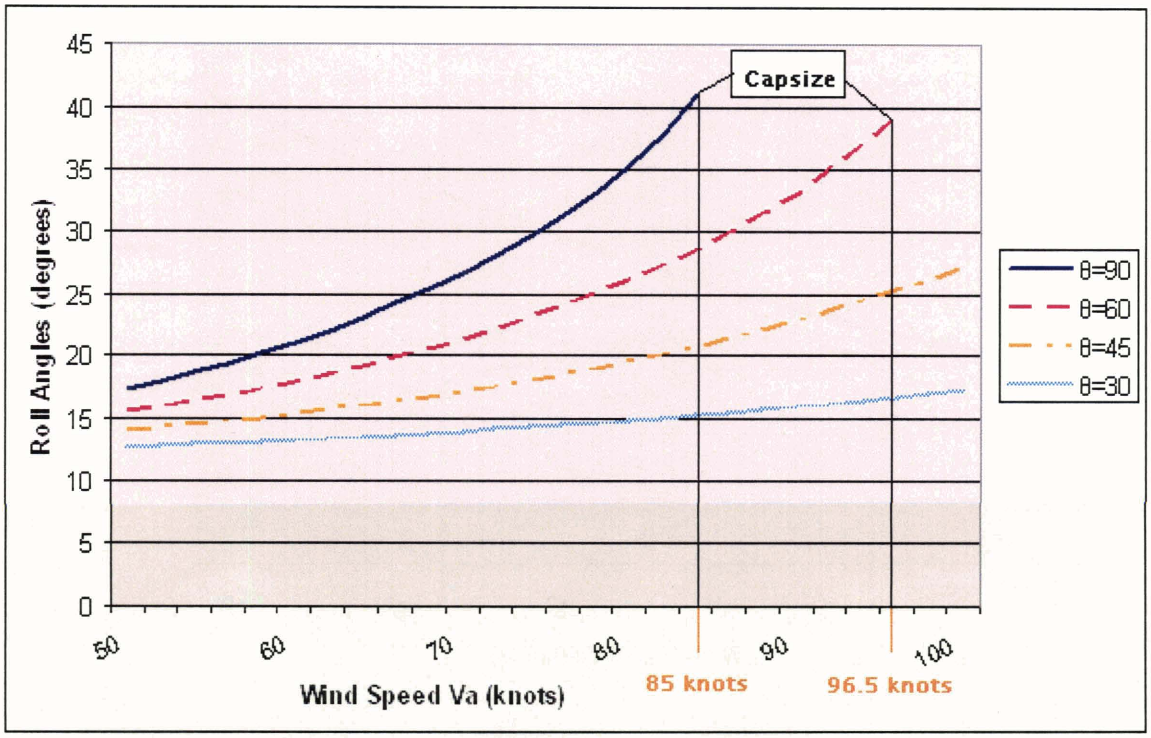


Figure 47: Maximum Roll Angles For Dynamic Case (Tumblehome GM=1.5m)

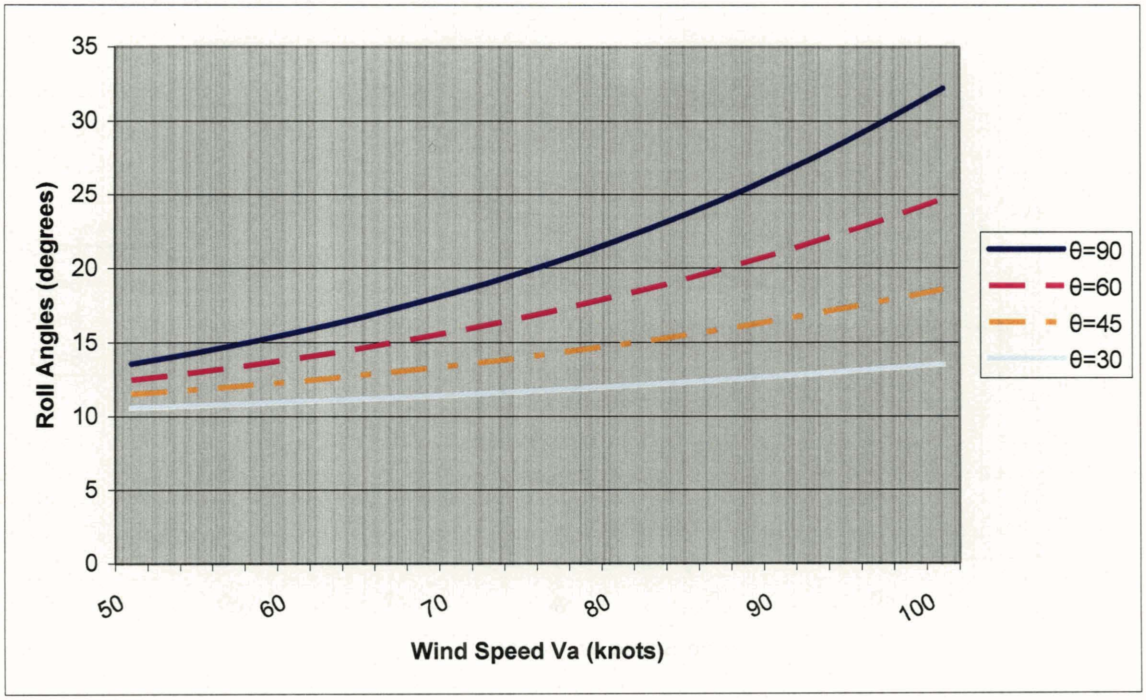


Figure 48: Maximum Roll Angles For Dynamic Case (Tumblehome GM=2.0m)

Wall Sided Hull Form

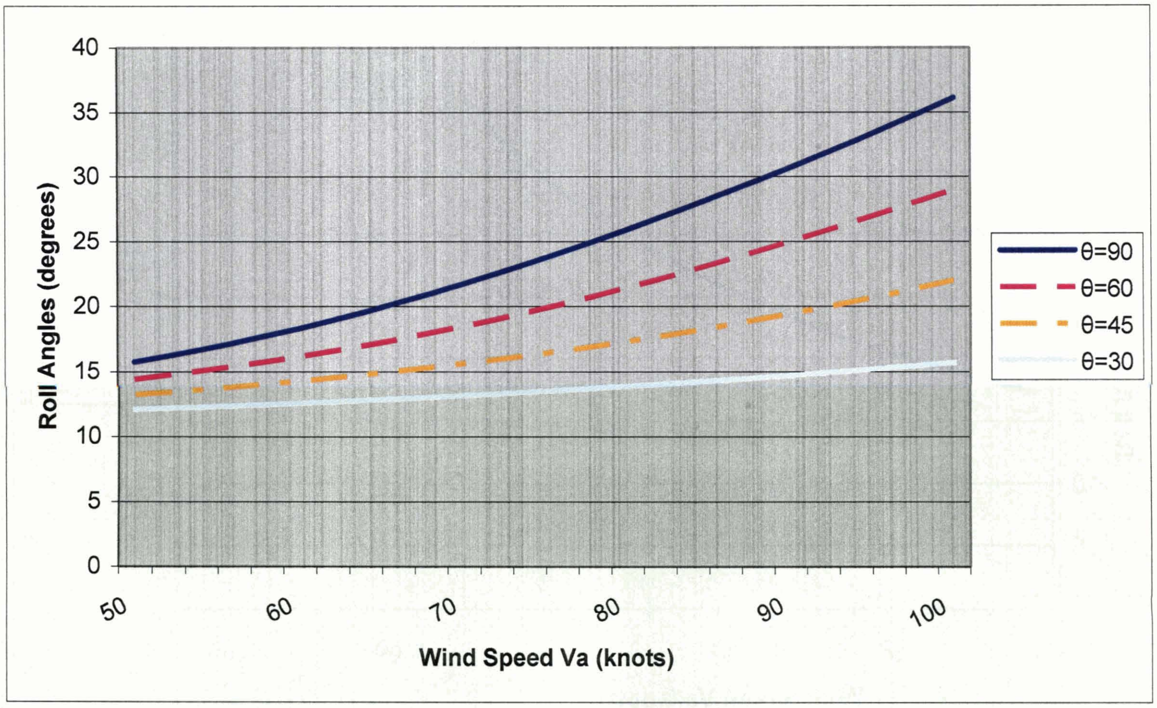


Figure 49: Maximum Roll Angles For Dynamic Case (Wall Sided GM=1.5m)

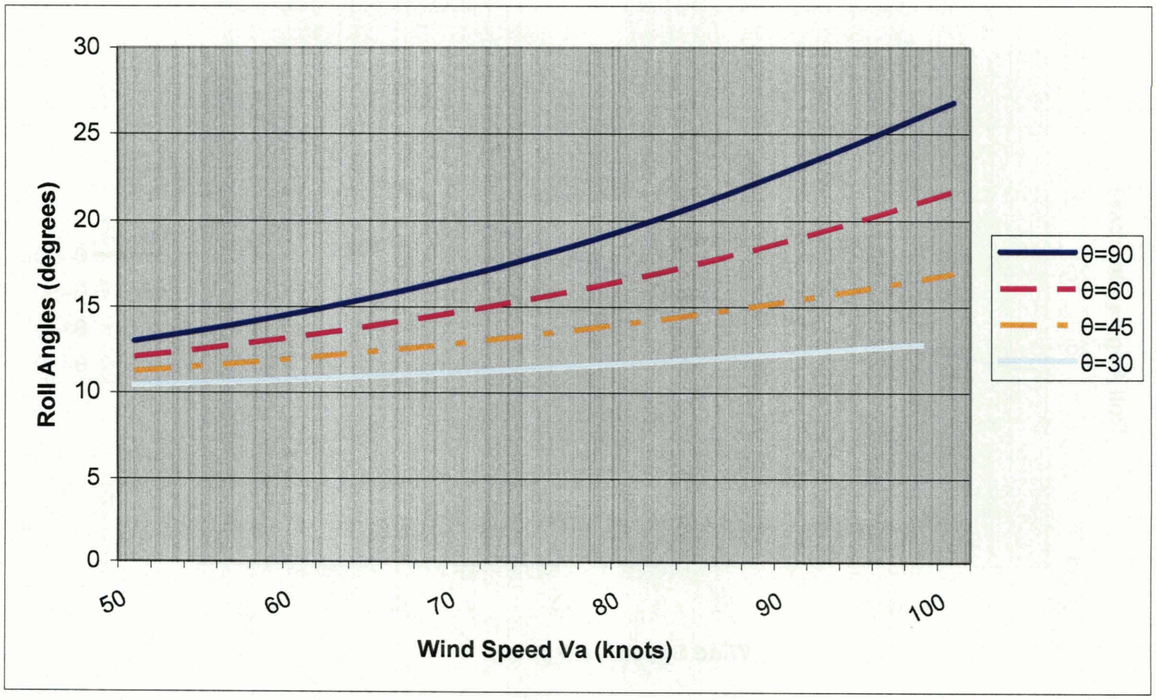


Figure 50: Maximum Roll Angles For Dynamic Case (Wall Sided GM=2.0m)

Flare-Sided Hull Form

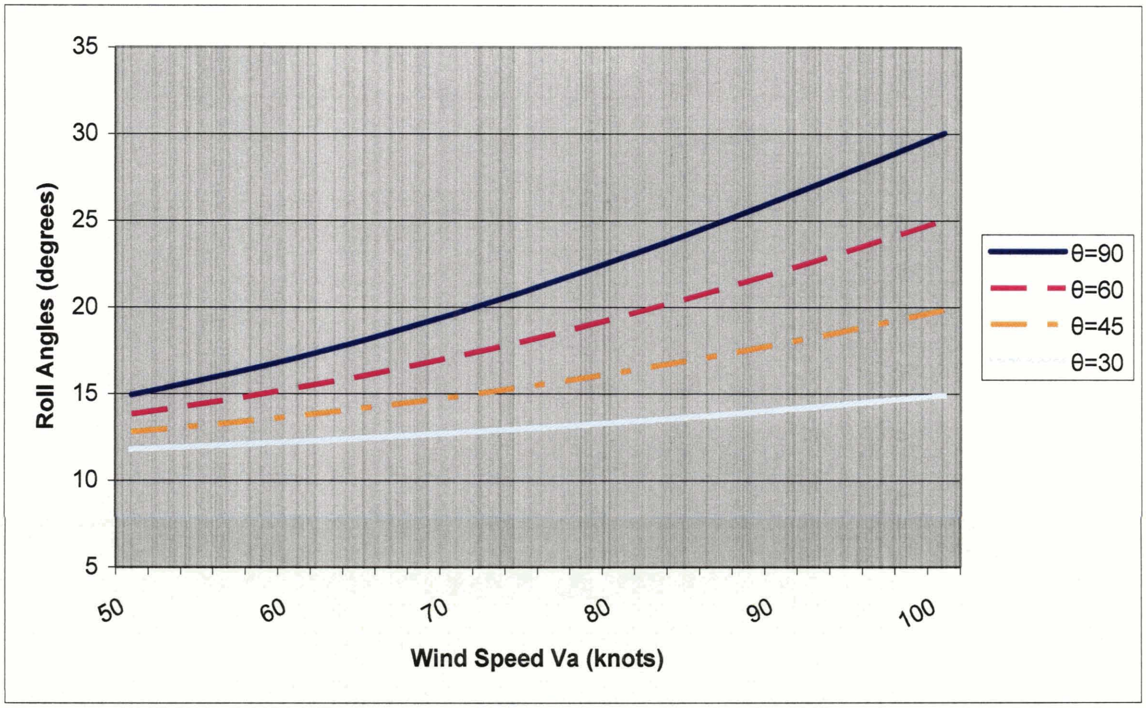


Figure 51: Maximum Roll Angles For Dynamic Case (Flare Sided GM=1.5m)

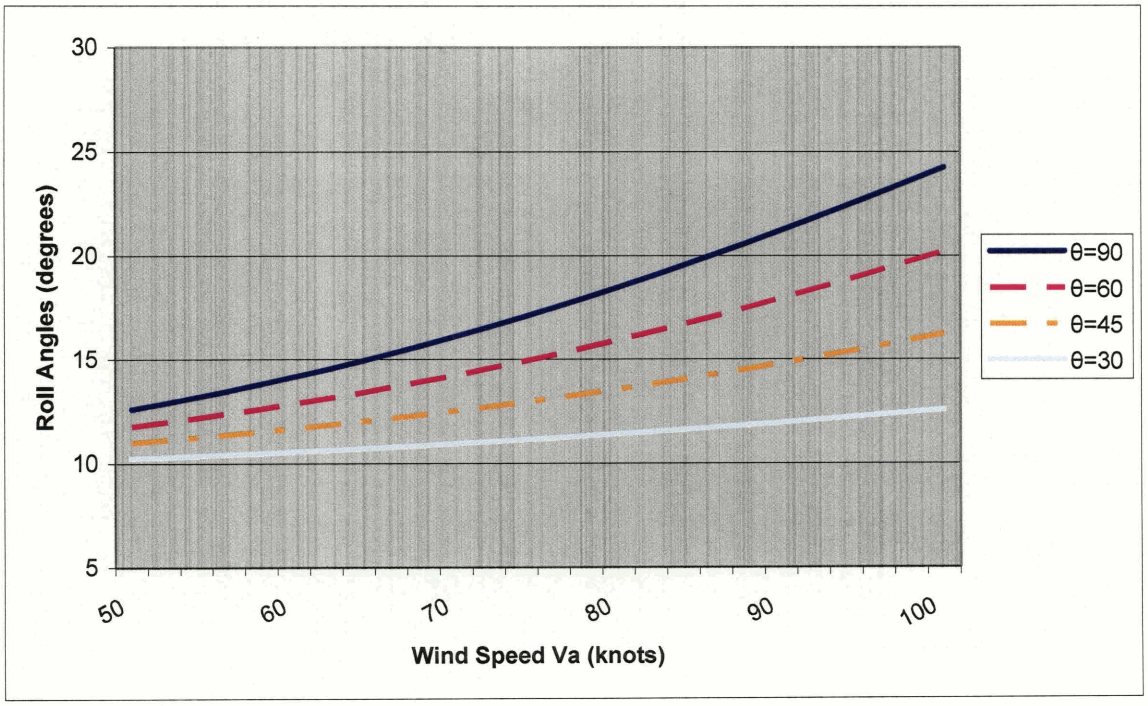


Figure 52: Maximum Roll Angles For Dynamic Case (Flare Sided GM=2.0m)

Appendix VII: Data For Bulk-Carriers Losses

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
Barge Carrier	13-Dec-78	MUNCHEN	46249	37134	0	28	Lash Barges Steel/Steel Products
Bulk Carrier	5-Jan-78	CHANDRAGUPTA	37685	21635	0	69	Grain Wheat
Bulk Carrier	15-Jan-78	EVELPIDIS ERA	31353	10451	0		Rock Salt
Bulk Carrier	1-Feb-79	MITSOS	19978	10984	0		Scrap Iron
Bulk Carrier	24-Dec-79	HONGJIN	56127	33461	0		
Bulk Carrier	7-Jan-80	AGIOS GIORGIS	27624	16565	0	29	Scrap
Bulk Carrier	13-Aug-80	THEOMITOR	51717	25691	0		Iron Ore
Bulk Carrier	27-Nov-80	SANDALION	46050	26389	0		Coal
Bulk Carrier	27-Dec-80	ARTEMIS	30190	17770	0		Timber
Bulk Carrier	30-Dec-80	ONOMICHI MARU	56341	33833	0		Coal 53,000 Tons
Bulk Carrier	2-Jan-81	GOLDEN PINE	20349	11738	0	25	Copper Concentrate
Bulk Carrier	7-Mar-81	MEZADA	31554	19247	12	12	Potash
Bulk Carrier	29-Dec-81	MARINA DI EQUA	32818	22901	0	30	Steel Plates Steel Coils
Bulk Carrier	12-Feb-83	MARINE ELECTRIC	25985	13757	24	9	Coal, 27000 Tons
Bulk Carrier	28-Jan-84	THOMAS K.	20829	14218	1	7	Scrap Iron
Bulk Carrier	16-Jul-84	ANTACUS	26044	16347	0		Steel 24,600 Tons
Bulk Carrier	9-Aug-84	CHAR YE	16211	9936	0		
Bulk Carrier	9-Jun-85	WINNERS BEE	16769	9994	0		
Bulk Carrier	16-Aug-85	PAB	19472	12262	0		Pig Iron 11,000 Tons Asbestos
Bulk Carrier	15-Jan-86	LUCHANA	14524	8250	1	3	Iron Ore - 13,000 T
Bulk Carrier	13-Jan-87	TESTAROSSA	115721	66903	0	30	Iron Ore
Bulk Carrier	29-Apr-87	SKIPPER I	27345	14474	0		Scrap Iron
Bulk Carrier	12-Jun-87	CUMBERLANDE	36978	21384	0		Ferro-Manganese Manganese Sinters
Bulk Carrier	22-Jun-87	STAR CARRIER	25110	15992	0		Scrap Iron 22,400 T
Bulk Carrier	23-Jun-87	DAYSPRING	21241	13373	0		Manganese Ore Lead Concentrates
Bulk Carrier	24-Jul-87	ALBORADA	19112	10396	18	12	Coal - 17000 Tons
Bulk Carrier	4-Jul-88	SINGA SEA	26586	15894	1	18	Mineral Sands Copper Ore
Bulk Carrier	17-Apr-89	STAR OF ALEXANDRIA	35967	22627	0	2	Cement
Bulk Carrier	29-Apr-89	SEVASTI	15147	9042	0		Timber
Bulk Carrier	4-May-89	HURON	16895	9440	0	13	Timber Steel Scrap
Bulk Carrier	4-Oct-89	PAN DYNASTY	36650	21567	0		Phosphate Rock

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
Bulk Carrier	29-Dec-89	VULCA	42245	19851	0		Scrap Iron
Bulk Carrier	7-Jan-90	ORIENT PIONEER	108504	51506	0		Iron Ore
Bulk Carrier	23-May-90	TAO YUAN HAI	122734	64920	0		Iron Ore
Bulk Carrier	31-Jul-90	CORAZON	28757	15892	6		Cement
Bulk Carrier	18-Dec-90	ELOUNDA DAY	38250	20966	0		Potash
Bulk Carrier	11-Jan-91	PROTEKTOR	80185	43218	0	33	Iron Ore
Bulk Carrier	21-Jan-91	CONTINENTAL LOTUS	53346	29966	26	12	Iron Ore 51,600t
Bulk Carrier	30-Jul-91	SUNSET	20932	13907	0		Steel Products
Bulk Carrier	24-Aug-91	MELETE	72063	35489	0	25	Iron Ore
Bulk Carrier	21-Oct-91	ERATO	29098	16616	1	5	Phosphates
Bulk Carrier	27-Nov-91	ENTRUST FAITH	63533	35014	0		Iron Ore
Bulk Carrier	30-May-92	GREAT EAGLE	65230	31507	0		Iron Ore 60,715t
Bulk Carrier	15-Mar-93	GOLD BOND CONVEYOR	26459	14941	1	32	Gypsum
Bulk Carrier	26-May-93	NAGOS	74543	36981	0	17	Coal
Bulk Carrier	3-Feb-94	CHRISTINAKI	26510	16401	0	27	Scrap Metal
Bulk Carrier	25-Feb-94	KAMARI	127283	58896	0		Iron Ore 120,000t
Bulk Carrier	20-Jun-94	APOLLO SEA	131305	67914	0	36	Iron Ore (124,000t)
Bulk Carrier	22-Dec-95	MEMED ABASHIDZE	38250	23198	0	3	Steel Bars Soda Ash
Bulk Carrier	9-Feb-96	INNOVATOR	20009	12181	0		Gypsum In Bulk
Bulk Carrier	17-Feb-96	SEAFAITH	68275	35427	0	19	Iron Ore
Bulk Carrier	14-Sep-96	IOLCOS VICTORY	132597	74278	5		Minerals
Bulk Carrier	8-Feb-97	LEROS STRENGTH	21673	12998	0	20	Apattit Ore
Bulk Carrier	18-Feb-97	ALBION TWO	26976	16278	25		Steel Products
Bulk Carrier	16-Jan-98	FLARE	29222	16947	17	4	
Bulk Carrier	2-Aug-98	ASEAN CARRIER	16873	9997	0		Bagged Cement
Bulk Carrier	5-Sep-99	WELL SPEEDER	26587	16184	0		Cement
Bulk Carrier	11-Oct-99	SANAGA	24732	14929	0		Logs
Bulk Carrier	21-Dec-99	XIN ZHU JIANG	35660	22020	0	1	Ore
Bulk Carrier	23-Mar-00	LEADER L	62322	38975	6	12	Salt
Bulk Carrier	14-Jun-00	TREASURE	143731	76705	0		Iron Ore
Bulk Carrier	16-Sep-00	MADONA	33037	20122	0		Cement
Bulk Carrier	12-Sep-01	KAMIKAWA MARU	149532	77269	0	10	Iron Ore

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
Bulk Carrier	22-Dec-01	CHRISTOPHER	164891	83784	0	27	Coal
Bulk Carrier	24-Feb-04	ASIAN NOBLE	12336	7170	0	1	Coal
Bulk Carrier	18-Nov-05	BRIGHT SUN	37574	22271	0	1	
Bulk Carrier	13-Mar-06	BANG XING I	19816	11641	0		Logs
Bulk Carrier	12-Dec-80	D. G. KERR	13910	8017	0		
Bulk Carrier	30-Dec-87	THOMAS WILSON	16866	8758	0		
Bulk Carrier	3-Dec-95	CANADIAN HARVEST	31413	18473	0		
Cement Carrier	30-Jan-90	FLAG THEOFANO	4470	2818	2	17	Bulk Cement
Cement Carrier	11-Feb-90	SCANTRADER	2784	1591	12	12	Cement; 2,400 Tonnes
Cement Carrier	6-Jan-93	COTY I	4064	2786	4	13	Cement
Cement Carrier	28-Dec-96	DYSTOS	6197	4045	17	3	Cement
Cement Carrier	25-Feb-02	FILIPPOS K II	1640	1227	0	1	Fertilizer
TOTAL	**76**		**3261035**	**1807729**	**179**	**618**	

Appendix VIII: Data for General Cargo Ships' Losses

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
General Cargo	11-Jan-78	HOLMAR I	631	461	1	4	Sprats
General Cargo	12-Jan-78	HERMANN-HELENE	438	299	0		Iron
General Cargo	12-Jan-78	ANNA GRAEBE	1050	487	0		Bulk Fertilizer
General Cargo	21-Jan-78	MARLEN	3464	1851	0		Cement,fibre Pipes Oil In Casks
General Cargo	21-Jan-78	WATI	6082	2992	12	3	Cement
General Cargo	29-Jan-78	KAPTAN ISMAIL HAKKI	1032	498	0		Zinc Oxide
General Cargo	3-Feb-78	MARIA DORMIO	1483	936	0		Pozzolana
General Cargo	6-Feb-78	KATRINA	3445	3445	0		Palm Oil Coconut Oil Chemicals
General Cargo	26-Feb-78	BLESSE	599	388	0		Scrap Iron
General Cargo	3-Mar-78	DIMITRIOS M	1016	906	0		Steel Bars
General Cargo	22-Mar-78	DOROTHEOS T	1999	1503	0		General
General Cargo	26-Mar-78	ELBE	859	500	0	1	Rye
General Cargo	11-May-78	ARO	362	285	1		Sand
General Cargo	28-May-78	WING ON	2737	1973	0		Barytes
General Cargo	14-Aug-78	TIEN PAO	3091	1937	0		Boxed Books
General Cargo	16-Aug-78	KIS OLE	305	200	0		
General Cargo	14-Sep-78	VOL	199	199	0		Anthracite Nuts
General Cargo	3-Oct-78	NYNES	300	119	0	2	Sand
General Cargo	11-Oct-78	WAHYUNI	5757	2995	0		
General Cargo	23-Oct-78	APOLLO 1	4756	2772	2	6	Logs
General Cargo	27-Oct-78	NIKO PRIMO	970	499	0	8	Cement Pipes
General Cargo	29-Oct-78	PETRAKIS	258	146	0		
General Cargo	8-Nov-78	RAYLIGHT	406	260	0		Slag Fertilizer,370t
General Cargo	10-Nov-78	ANNEMIEKE	2658	1421	0		Granite Chips
General Cargo	12-Dec-78	CLAVERIA CLIPPER	1540	999	4	4	Philippine Plywood
General Cargo	15-Dec-78	TEMO.	839	493	0		Barytes
General Cargo	24-Dec-78	ALSTERN	3670	2285	0		Paper
General Cargo	28-Dec-78	TENORGA	4300	3300	4	17	Steel
General Cargo	31-Dec-78	DECIMUM.	3079	1600	0		Cement Clinker
General Cargo	3-Jan-79	GERMA	2219	1240	9		Unknown Cargo

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
General Cargo	4-Jan-79	JOLIKA	965	576	0		
General Cargo	13-Feb-79	REVI	558	414	0		Silver Sand
General Cargo	15-Feb-79	TAISEI MARU	727	462	0		Gravel
General Cargo	15-Feb-79	IRIS	11540	8479	8		
General Cargo	28-Feb-79	JOHANN	732	399	0		Barley (600 Tons)
General Cargo	11-Mar-79	JASMINE	1179	499	1		
General Cargo	17-Mar-79	KORONOWO	3017	1593	0		Timber
General Cargo	6-Apr-79	KATYA	2242	1877	0		Paper
General Cargo	12-Apr-79	ELLI	2753	1599	0	1	General 2400 Tonnes
General Cargo	15-Apr-79	TORENIA	11707	8077	0		Raw Sugar 10000 Tons
General Cargo	3-Jul-79	MANSUR SIMAO	5282	3232	0		Wheat
General Cargo	15-Jul-79	NANDA DEVI	3214	1925	0		Bentonite
General Cargo	18-Jul-79	KOUN MARU No. 28	281	199	0		
General Cargo	24-Jul-79	TONG NAM	10052	6336	3	28	Chrome Ore
General Cargo	30-Aug-79	KAPTAN CELAL	3165	2123	0		Coal (3000tons)
General Cargo	14-Sep-79	REBECCA	2164	880	3	1	Soya In Bulk
General Cargo	19-Sep-79	AUSTRI	1056	499	4	1	Pig Iron
General Cargo	24-Sep-79	MAKEDONIA	1177	859	0		Canned Goods
General Cargo	29-Oct-79	AGIOS GERASSIMOS	813	600	0		Contrabandcigarettes
General Cargo	6-Nov-79	POOL FISHER	1394	1028	3	10	Potash
General Cargo	15-Nov-79	PETER SIF	4064	1599	0		General
General Cargo	15-Nov-79	CHUNDER	3465	1997	0		Logs
General Cargo	19-Nov-79	MARINA T	13447	8777	0	1	
General Cargo	26-Nov-79	JOHANNES L	793	489	0		
General Cargo	28-Nov-79	BLACK SEA	1941	1119	4	12	Fertiliser 1670 Tons
General Cargo	2-Dec-79	AKISHIMA MARU	6022	2998	0		Logs
General Cargo	5-Dec-79	WHESTSCHELDE	779	299	0		
General Cargo	6-Dec-79	MALMI	6896	4982	4	10	Coke
General Cargo	13-Dec-79	ANTONIO SCOTTO	1018	499	0		Tomato Sauce 950tons
General Cargo	20-Dec-79	LERT	609	388	0		Steel Castings
General Cargo	25-Dec-79	SOULA G	827	499	5	1	
General Cargo	31-Dec-79	PHENIX	879	493	7		Iron Rods Containers

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
General Cargo	4-Jan-80	BILL CROSBIE	2520	1598	0		Structural Steel Steel Grinding Balls
General Cargo	7-Jan-80	MARLA-K	294	294	0		Fertalizer 4096 Bags
General Cargo	22-Jan-80	ALEX	5890	2992	10	9	Lauan Logs (4287)
General Cargo	26-Jan-80	HENRY R II	186	186	0		
General Cargo	26-Jan-80	CARMEN R.	528	295	0		
General Cargo	26-Jan-80	RYUHO MARU NO. 3	680	442	0		Asbestos 450 Tons Tapioca & Wheat General
General Cargo	29-Jan-80	VICTORY MARCH	4983	3197	0	24	Ore
General Cargo	30-Jan-80	HATSUFUJI	9981	5130	2	20	Coal (7500 Tons)
General Cargo	31-Jan-80	SHINEI MARU	1231	499	4	1	
General Cargo	2-Feb-80	NISSEN MARU	1936	975	0	9	Coal 1100 Tons
General Cargo	16-Feb-80	EASTERN MINICON	1339	1616	0	30	General Containers
General Cargo	20-Feb-80	ANASTASIOS	1846	1846	0		
General Cargo	28-Feb-80	NAHEDA H.	495	495	0		Potatoes 600 Tons
General Cargo	12-Mar-80	MAURICE DESGAGNES	3485	2469	0		Railway Ties
General Cargo	15-Mar-80	TUSKAR-2	584	394	0		Bagged Cargo
General Cargo	22-Mar-80	KAIFUKU MARU NO. 13	1118	499	2		Limestone (820tonnes
General Cargo	29-Mar-80	GERMA GEISHA	5300	3259	0		Grain
General Cargo	20-Apr-80	ALTMARK	850	425	2		China Clay
General Cargo	11-Jun-80	SUNRISE	15562	10224	0		Cement, Bagged
General Cargo	12-Jul-80	BLUE RIVER	6702	4377	0		Steel
General Cargo	30-Jul-80	ATHLOS	14606	10732	0		Sugar, 14000 Tonnes
General Cargo	4-Aug-80	RANDA II	909	484	0		
General Cargo	7-Oct-80	RANDI DANIA	849	299	2		Genera Cargo
General Cargo	11-Oct-80	BULK CARRIER	2350	1599	0	1	Sulphur (2317 Tons)
General Cargo	17-Oct-80	SKYRIAN HOPE	12142	7745	0		General
General Cargo	25-Nov-80	CASTOR I	1016	500	0		
General Cargo	24-Dec-80	SANYU MARU NO. 8	1150	420	0		Maize
General Cargo	24-Dec-80	SIMRI	2449	1499	0		Iron
General Cargo	28-Dec-80	BASTABALES	1300	976	0		Semolina
General Cargo	29-Dec-80	GARSA TIGA	5859	3139	0	6	Logs
General Cargo	29-Dec-80	MAMMOTH SCAN	6650	4244	0		
General Cargo	15-Jan-81	GOODWILL	940	944	0		Chipboard 750 Tonnes

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
General Cargo	4-Jan-80	BILL CROSBIE	2520	1598	0		Structural Steel Steel Grinding Balls
General Cargo	7-Jan-80	MARLA-K	294	294	0		Fertalizer 4096 Bags
General Cargo	22-Jan-80	ALEX	5890	2992	10	9	Lauan Logs (4287)
General Cargo	26-Jan-80	HENRY R II	186	186	0		
General Cargo	26-Jan-80	CARMEN R.	528	295	0		
General Cargo	26-Jan-80	RYUHO MARU NO. 3	680	442	0		Asbestos 450 Tons Tapioca & Wheat General
General Cargo	29-Jan-80	VICTORY MARCH	4983	3197	0	24	Ore
General Cargo	30-Jan-80	HATSUFUJI	9981	5130	2	20	Coal (7500 Tons)
General Cargo	31-Jan-80	SHINEI MARU	1231	499	4	1	
General Cargo	2-Feb-80	NISSEN MARU	1936	975	0	9	Coal 1100 Tons
General Cargo	16-Feb-80	EASTERN MINICON	1339	1616	0	30	General Containers
General Cargo	20-Feb-80	ANASTASIOS	1846	1846	0		
General Cargo	28-Feb-80	NAHEDA H.	495	495	0		Potatoes 600 Tons
General Cargo	12-Mar-80	MAURICE DESGAGNES	3485	2469	0		Railway Ties
General Cargo	15-Mar-80	TUSKAR-2	584	394	0		Bagged Cargo
General Cargo	22-Mar-80	KAIFUKU MARU NO. 13	1118	499	2		Limestone (820tonnes
General Cargo	29-Mar-80	GERMA GEISHA	5300	3259	0		Grain
General Cargo	20-Apr-80	ALTMARK	850	425	2		China Clay
General Cargo	11-Jun-80	SUNRISE	15562	10224	0		Cement, Bagged
General Cargo	12-Jul-80	BLUE RIVER	6702	4377	0		Steel
General Cargo	30-Jul-80	ATHLOS	14606	10732	0		Sugar, 14000 Tonnes
General Cargo	4-Aug-80	RANDA II	909	484	0		
General Cargo	7-Oct-80	RANDI DANIA	849	299	2		Genera Cargo
General Cargo	11-Oct-80	BULK CARRIER	2350	1599	0	1	Sulphur (2317 Tons)
General Cargo	17-Oct-80	SKYRIAN HOPE	12142	7745	0		General
General Cargo	25-Nov-80	CASTOR I	1016	500	0		
General Cargo	24-Dec-80	SANYU MARU NO. 8	1150	420	0		Maize
General Cargo	24-Dec-80	SIMRI	2449	1499	0		Iron
General Cargo	28-Dec-80	BASTABALES	1300	976	0		Semolina
General Cargo	29-Dec-80	GARSA TIGA	5859	3139	0	6	Logs
General Cargo	29-Dec-80	MAMMOTH SCAN	6650	4244	0		
General Cargo	15-Jan-81	GOODWILL	940	944	0		Chipboard 750 Tonnes

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
General Cargo	17-Jan-81	DENIZ SONMEZ	6359	4259	0	34	Phosphate In Bulk
General Cargo	8-Feb-81	TENIA II	2140	1333	3	5	Wire Rolls
General Cargo	14-Feb-81	EASTERN MARINER 1	12163	7965	0		Phosphates In Bags
General Cargo	16-Feb-81	PYENG HAE	610	449	0		Limestone 685 Tons
General Cargo	26-Feb-81	KOMSOMOLETS NAKHODKI	8230	5923	18	17	Steel Products
General Cargo	27-Apr-81	SIRI MARIA	494	346	0		Sodium Phosphate
General Cargo	23-Jul-81	MELON KING	7908	4815	0		Steel Sheets
General Cargo	31-Jul-81	FATEMA	780	387	0		Crushed Lentils
General Cargo	1-Sep-81	JUNTOKU MARU NO. 3	430	199	0		
General Cargo	18-Sep-81	TUNGUFOSS	1327	1362	0		Meal
General Cargo	25-Sep-81	WAKAEBISU MARU NO. 8	311	197	0		
General Cargo	23-Oct-81	ASIA SPICA	5926	2997	0		Logs
General Cargo	3-Nov-81	DRAGON III	4267	2547	0		Logs
General Cargo	8-Nov-81	EMERALD	4152	2193	0	9	Aggregates Steel Mesh
General Cargo	19-Nov-81	BEATRIS	447	264	2		Macadam
General Cargo	29-Nov-81	NAROS	1256	499	0	1	Anchor Cables Timber
General Cargo	30-Nov-81	SHOKAI MARU	5855	3507	4	11	Coal
General Cargo	1-Dec-81	YUSEI MARU NO. 12	1200	476	1		Gravel
General Cargo	1-Dec-81	THIDATARA	2123	980	6		Barite Ore 1800 M To
General Cargo	2-Dec-81	CRYSTAL STAR	5100	3046	0	1	Lauan Logs
General Cargo	11-Dec-81	BRATSTVO	2390	1580	1	8	
General Cargo	13-Dec-81	BOBRIX	965	647	0	1	Maize
General Cargo	14-Dec-81	GRAINVILLE	2753	1777	1	2	Scrap Iron
General Cargo	16-Dec-81	NISSHIN MARU	1944	694	0		
General Cargo	17-Dec-81	MARK	965	499	1	5	China Clay
General Cargo	20-Dec-81	SING YONG	618	618	0	1	General
General Cargo	21-Dec-81	HAFA ADAI	509	539	0		
General Cargo	9-Jan-82	GOODWILL	655	655	0		
General Cargo	14-Jan-82	NANDI	5905	2995	0		Timber
General Cargo	5-Mar-82	FUKUTOKU MARU NO. 1	780	495	0		
General Cargo	6-Mar-82	ZOE II	5268	2650	0		Timber Rice (Bagged)
General Cargo	7-Mar-82	NIKOSNASOS II	6641	4156	0		Cement

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
General Cargo	13-Mar-82	RISNES	835	295	1		Fertilizer
General Cargo	25-Mar-82	SUDURLAND	1790	1143	0	1	Salt, 1110 Tons,
General Cargo	4-Apr-82	CHOEI MARU NO. 5	337	196	0		
General Cargo	4-Apr-82	ZEIDA	2840	1594	7	3	Planks Steel Coils Wood
General Cargo	13-Apr-82	SUMIYOSHI MARU NO. 8	199	199	0		
General Cargo	18-Jun-82	YUSEI MARU NO. 21	1200	499	0		
General Cargo	29-Jun-82	NEW GALAXY	942	938	0		Wheat Bran
General Cargo	4-Aug-82	QUIZANDAL	1000	668	0		Waste Paper
General Cargo	25-Aug-82	EASTERN PROGRESS	5747	3628	0		
General Cargo	17-Oct-82	KARYA TAMBANGAN	170	140	0	55	Passengers General Cargo
General Cargo	28-Oct-82	STAR RIVER	339	339	0	1	Salt
General Cargo	3-Nov-82	KALIMANTAN LIMA	6026	2994	0		Logs, 5503 Tons
General Cargo	8-Nov-82	NISSOS ANDROS	4484	2916	19		Ceramics Marble
General Cargo	10-Nov-82	NEPTUNE SKY	4185	2500	0		Logs, 3700 Cubic M.
General Cargo	14-Nov-82	NESAM	2364	1571	4	1	Phosphates
General Cargo	25-Nov-82	BRILLIANTE	1465	1056	0		Lumber
General Cargo	27-Nov-82	ILIANA	3079	1598	0		
General Cargo	12-Dec-82	FLORECIMIENTO	6472	3550	0		Logs
General Cargo	14-Dec-82	JALAMORARI	13819	9612	1		Woodpulp Asbestos
General Cargo	17-Dec-82	BETTY S	840	485	0		Rolls Of Paper
General Cargo	26-Dec-82	CARIGULF WARRIOR	1052	495	0		Lumber
General Cargo	28-Dec-82	MILLION NO. I	1798	922	0		Cement
General Cargo	29-Dec-82	SINE S	163	113	1		Ref. Cargo 82 Tons
General Cargo	7-Jan-83	BAMBOO ROOT	13396	8820	0		Manganese Ore
General Cargo	17-Jan-83	NEW SILLA	5664	4170	0		Logs
General Cargo	20-Jan-83	KUDOWA ZDROJ	1920	1991	19	1	Iron Rods General Containers
General Cargo	23-Jan-83	KAPTAN HASAN HANTAL	793	496	0	11	Iron Ore, 1000 Tons
General Cargo	5-Feb-83	HOSEI MARU	893	499	0		Silicon Sand 800 Ton
General Cargo	11-Feb-83	MAYA	1752	1598	7		Scrap Iron - 1200 T
General Cargo	19-Feb-83	NIKOS	2497	821	0		Cement
General Cargo	24-Feb-83	POLMAR	1494	1112	0		
General Cargo	18-Mar-83	JASA	5661	2992	1	11	4000 Tons Logs

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
General Cargo	26-Mar-83	SPRING LASS	680	432	0		Wire Mesh
General Cargo	22-Apr-83	MILHAFRE	1683	999	1		Containers Iron Tubes
General Cargo	26-Apr-83	HARAPAN II	132	114	0	42	Passengers (78) Livestock (Cows) Rice & Gen Cargo
General Cargo	6-Jun-83	ENO	830	500	2	1	Chain
General Cargo	17-Jun-83	ESTEDEICH	2350	915	0		General
General Cargo	27-Jun-83	KINABALU LIMA	6210	3629	0		Steel Plates
General Cargo	29-Jun-83	CONESTHMUS	499	383	0		
General Cargo	29-Aug-83	RAUNEFJORD	422	199	0	4	
General Cargo	12-Sep-83	RENATE S	864	499	0	4	Bulk Zinc
General Cargo	3-Oct-83	CHRISTOFOROS	2774	1586	0		Cement
General Cargo	11-Oct-83	KYODO MARU	195	146	0		Roofing Tiles
General Cargo	18-Oct-83	NAEROYSUND	278	251	0		Cement
General Cargo	1-Nov-83	KAMPEN	6300	3982	7		Coal (5300 Tons)
General Cargo	18-Nov-83	TOHO MARU NO. 12	1099	491	1	1	Gravel 910 Tons.
General Cargo	21-Nov-83	DAI LUNG	6289	4016	1	1	Round Logs 6219 Cu M
General Cargo	30-Nov-83	KAYU LAPIS SATU	4906	2970	0		Logs (4,120 Cu M)
General Cargo	8-Dec-83	LAT DA	1759	998	0		
General Cargo	9-Dec-83	KAREN FOLMER	706	300	0		Fertilizer
General Cargo	22-Dec-83	SAINT DRAGON	2675	1520	0		
General Cargo	29-Dec-83	LIBRA	498	498	0		Phosphate Machinery
General Cargo	30-Dec-83	GREEN MERCURY	5928	3018	0		Coal, 5,320 Tonnes
General Cargo	23-Jan-84	RADIANT MED	5617	2997	14	2	Wheat In Bulk 4,500t Maize 500 Tons
General Cargo	27-Jan-84	SPAN	5135	2997	0		Logs
General Cargo	27-Jan-84	SEVEN AMBASSADOR	5974	3275	2	13	Logs
General Cargo	2-Feb-84	APOLLONIA V	1059	499	0	3	Cement
General Cargo	7-Feb-84	MIDNIGHT SUN I	5101	2531	8		Dunite 4800 T
General Cargo	9-Feb-84	OMEGA LADY	1067	734	0		Sulphur-840 Tonnes
General Cargo	19-Feb-84	TATIANA	657	395	0		Cement Passengers
General Cargo	26-Feb-84	CANDORA	402	415	0		
General Cargo	26-Feb-84	GUARNIZO	770	527	0		Pozzolana

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
General Cargo	11-Mar-84	ANDROMACHE I	834	495	0		
General Cargo	13-Mar-84	SONIA G. MASIQUES	559	363	0	7	Cement 460 Tons
General Cargo	28-Mar-84	URLEA	835	480	1		Wood 399 Tons
General Cargo	9-Apr-84	UNGGULI IV	550	449	0		Coffee Beans 423 T
General Cargo	6-Jun-84	JENNIES	16074	9172	0		Iron Pipes Magnesium
General Cargo	19-Jun-84	VELA VI	648	468	0		Onions
General Cargo	29-Jun-84	HAMAD AL KULAIB	2910	1597	0		Livestock
General Cargo	4-Jul-84	AL REAFA I	3539	2392	0		
General Cargo	14-Jul-84	CARIBE	2253	1415	1		Copper Zinc
General Cargo	21-Jul-84	MARIA RAMOS	5273	3233	3	8	Salt
General Cargo	29-Jul-84	ILSHIN GLORY	1618	1158	1	11	Mill Scale - 1500 T
General Cargo	7-Aug-84	ORIENTAL PEARL	8182	5139	0		Copper Concentrate
General Cargo	8-Aug-84	GINREI MARU	4603	2627	0		Logs
General Cargo	15-Aug-84	MARINA DEL SUR	5745	2991	0	4	
General Cargo	2-Sep-84	CASTOR	3040	1996	22		Pipes
General Cargo	6-Sep-84	MARINA	5405	4116	0		Phosphate
General Cargo	20-Oct-84	LIBRA	467	300	0		Scrap
General Cargo	20-Oct-84	LADY ODIEL	901	487	1	3	Steel Pipes - 765 T
General Cargo	15-Nov-84	PANOREA	991	445	4	3	General
General Cargo	17-Nov-84	INGMAR	849	422	0		Grain
General Cargo	20-Nov-84	CHEROKEE	1914	999	1	8	Lumber
General Cargo	21-Nov-84	FYLRIX	945	637	0		Granite Chippings
General Cargo	22-Nov-84	WU HANG	1520	795	0		Clay 1,000 Tons General
General Cargo	23-Nov-84	GOLFSTROM	1207	499	0		Wood
General Cargo	2-Dec-84	BLUE ANGEL	4962	2832	0	3	Logs
General Cargo	4-Dec-84	ARAUCA	3860	2403	0		General/In Container
General Cargo	5-Dec-84	SOFIA	2050	1219	0		Chickpeas Barbed Wire
General Cargo	23-Dec-84	GOLDEN PINE	8638	5390	0		Lauan Logs 6600 Tons
General Cargo	29-Jan-85	HWAPYUNG ACE	3413	1992	7	10	Containers, 57
General Cargo	1-Feb-85	CRYSTAL NO. 1	1618	993	1	13	Steel Materials
General Cargo	8-Feb-85	BUSKO ZDROJ	1902	1974	10	14	Steel Members
General Cargo	9-Feb-85	KOEI MARU NO. 11	813	395	0		Steel

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
General Cargo	22-Feb-85	SITI FREDA	6564	3675	0		Logs
General Cargo	10-Mar-85	YASMAT	6787	3986	0		Logs 1,753 Pieces
General Cargo	7-Apr-85	CAROLINE	720	414	0		Fertilizer
General Cargo	14-Apr-85	SANKO MARU	5935	2998	0		Logs 4,900 Tons
General Cargo	24-Jun-85	CAROL	1907	1051	0		Scrap
General Cargo	27-Jun-85	AL RUBAYIA	1438	869	0		
General Cargo	12-Aug-85	PORTVAG	564	299	0		Sand
General Cargo	8-Oct-85	OCEAN MACKEREL	524	424	0		
General Cargo	13-Oct-85	HOELIEN	4044	3278	0		Timber Steel
General Cargo	16-Oct-85	HANNA MARJUT	927	499	0	4	Sugar Beet
General Cargo	20-Oct-85	KRITI	833	481	0	7	Pumice, 720 Tons
General Cargo	23-Oct-85	HAI CHIANG	1563	937	1	17	Empty Gas Cylinders China Clay
General Cargo	3-Nov-85	GWYN	1552	730	0		Steel
General Cargo	10-Nov-85	RONA	555	299	0		Fishmeal Hay
General Cargo	17-Nov-85	JUNG KEUM NO. 7	1043	730	6	4	Mild Steel 850 Tons
General Cargo	26-Nov-85	NEGWAN	1556	1333	0		
General Cargo	28-Nov-85	SUSAN MITCHELL	395	292	0		'galvanise'
General Cargo	19-Dec-85	GLENDA	3263	1937	0	12	Fertiliser
General Cargo	27-Dec-85	KUNIEI MARU NO. 18	1570	498	0	2	Salt, 950 Tons
General Cargo	1-Jan-86	MORNING PARK	6308	4051	0		Logs
General Cargo	17-Jan-86	AGIOS NIKOLAOS	499	499	0		
General Cargo	23-Jan-86	STANLEY BAY	5558	3192	2	1	Minerals
General Cargo	30-Jan-86	ALPRO	945	713	2	5	China Clay
General Cargo	11-Feb-86	UNITY II	1118	490	7	2	General
General Cargo	17-Feb-86	NEMOS	9861	4981	7	1	Timber 9,500 Tons Logs
General Cargo	26-Feb-86	ANGELA SMITS	7800	3971	0		Ammonium Nitrate
General Cargo	28-Feb-86	LORENZO CONTAINER VII	1757	979	0	1	Logs
General Cargo	2-Mar-86	HALIM METE	1396	497	0		Ore
General Cargo	11-Mar-86	MARIA PIA M.	1927	983	0		General, 1,760 Tonne
General Cargo	23-Mar-86	SHOEI MARU	3115	1107	2	5	Coal 3,000 Tons
General Cargo	24-Mar-86	ERICA II	2345	1420	1	8	
General Cargo	25-Mar-86	AMINA	1005	493	3	2	

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
General Cargo	20-Apr-86	VIOLET MITCHELL	473	362	1	1	
General Cargo	15-Jun-86	DE BAO	4870	3995	3		Steel Bars 3324tonne
General Cargo	22-Jul-86	DELTA QUEEN	1040	498	0		Cement-850 Tonnes
General Cargo	12-Aug-86	EAMACO	13358	8146	1	17	Plywood
General Cargo	15-Aug-86	SALIM ATASOY	1000	498	0		
General Cargo	24-Aug-86	REHEMA	620	443	0		Gelignite 60t
General Cargo	25-Aug-86	SOPOT	3645	3008	0		Orange Pulp
General Cargo	4-Oct-86	DONG NAM	5701	3003	0		Timber
General Cargo	2-Nov-86	YEN KIM	5158	2831	0		Logs
General Cargo	16-Nov-86	HYMETUS	15281	9078	1	1	Steel
General Cargo	21-Nov-86	DA COSTA	295	125	0		Bagged Cement
General Cargo	2-Dec-86	VILLON	677	437	0		Barley
General Cargo	8-Dec-86	WESERBERG	1900	998	0		Cornflour
General Cargo	21-Dec-86	BUMI PERSADA	3300	1592	0		General
General Cargo	24-Dec-86	SUDURLAND	2333	2333	3	3	Salted Herring
General Cargo	13-Jan-87	VISHVA ANURAG	14580	11179	0		Steel General Containers
General Cargo	14-Jan-87	ALBATROS	394	229	0		Grain-300 Tonnes Fishmeal Soyabeans
General Cargo	17-Jan-87	KYTHERA STAR	3581	3163	3	15	Iron Bars
General Cargo	18-Jan-87	NIKOLAOS L.	904	500	0	10	Bricks 630t Passengers
General Cargo	6-Feb-87	CAMMING	6092	3529	7	16	Logs
General Cargo	12-Feb-87	BORA ISIK	7591	5174	0	3	Borax Steel
General Cargo	24-Feb-87	BALSA 24	6638	3724	4	14	Clay
General Cargo	6-Mar-87	CAPTAIN FRED	693	538	0		
General Cargo	14-Mar-87	KOMSOMOLETS KIRGIZII	12844	8540	0		Flour 10292t
General Cargo	23-Mar-87	STEFAN E	2223	1189	1		
General Cargo	8-Jul-87	AVA MINTI	4767	2872	3	16	Salt
General Cargo	8-Jul-87	CONTI BELGICA	6140	3987	0		General 1650 Tons
General Cargo	13-Jul-87	MINDE	764	299	0		Small Stones
General Cargo	20-Jul-87	DON TONY	800	581	0		
General Cargo	26-Aug-87	BEHRAM DUBASH-I	606	431	0		Clinker 585 Tons
General Cargo	16-Oct-87	SUMNIA	3283	1595	0	2	

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
General Cargo	28-Nov-87	KAKAS	6276	3716	1	1	Lauan Logs
General Cargo	6-Dec-87	JANG YUNG No. 2	570	294	0	11	Timber
General Cargo	14-Dec-87	TRITON TRADER	3132	3132	0		Fibreboard
General Cargo	13-Jan-88	SUDARWAN I	175	175	0	1	General 200 Tons
General Cargo	24-Jan-88	CELIKTRANS II	1400	499	0	1	Metal
General Cargo	29-Jan-88	ROLANDIA	4801	2723	0	12	Alumina In Bulk
General Cargo	3-Feb-88	NAUTILUS	3095	1599	0		
General Cargo	31-Mar-88	EL EXPORTADOR	1811	1355	0		Salt - 2000 Tons
General Cargo	7-Apr-88	TOMIYAMA MARU No. 5	399	198	1	4	Wooden Chips 350 T
General Cargo	18-Apr-88	SANDAKAN	3860	2878	0		Copper Sulphide
General Cargo	7-May-88	ABOUDY	854	499	0		Aluminium 122 T Livestock General
General Cargo	25-Jun-88	WALIAN	2194	997	1		Drilling Cement
General Cargo	29-Jun-88	MIRENE	7449	4997	0		Fertiliser Base
General Cargo	26-Sep-88	ARDLOUGH	2315	998	0		Hydrogen Peroxide Sodium Hypochlorite
General Cargo	10-Oct-88	CENTRAL CRUISER	5313	3000	1	3	Logs
General Cargo	30-Oct-88	HUNG MING No. 1	6025	3571	0		
General Cargo	30-Oct-88	MARIA PILAR	6316	3961	0		Logs
General Cargo	18-Nov-88	LA VIE EN ROSE	7123	4415	2	1	Malaysian Timber
General Cargo	24-Nov-88	KATIA	7500	4940	0		Hemp
General Cargo	2-Dec-88	SADU	4737	3531	0		
General Cargo	9-Dec-88	FOUR STAR I	1904	1982	0	3	Marble General
General Cargo	10-Dec-88	CAMFAIR	6667	4169	0		Logs
General Cargo	11-Dec-88	SELINA	8034	4827	0		Lumber
General Cargo	26-Dec-88	BADEN	822	297	0		Steel
General Cargo	22-Feb-89	SECIL ANGOLA	4842	2625	5	12	Salt
General Cargo	24-Feb-89	WALTRAUD	2964	2726	0		Containers
General Cargo	25-Feb-89	ANNA LEONHARDT	6552	3894	1	14	Alumina 6000t
General Cargo	28-Feb-89	POLARLIGHT	424	199	0		Cement
General Cargo	9-Mar-89	LORENZO CONTAINER V	2000	995	19		Foodstuffs Construction Mats.
General Cargo	13-Mar-89	PERINTIS	1683	999	0		Containers Toxic Chemicals
General Cargo	29-Mar-89	DIAS	838	499	0		

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
General Cargo	31-Mar-89	RAHIM 3	5778	2958	16	4	Scrap Metal 5,300 T
General Cargo	10-Apr-89	KOBA	4084	2300	0	1	Sorghum Grain
General Cargo	16-Apr-89	HYSTEIN	2503	1391	0		Grain
General Cargo	13-Jun-89	PUERTO PLATA	3085	1589	0		Gypsum
General Cargo	28-Jun-89	HWAN YANG	4613	2745	0		Polyester Yarn Polyester Chip Paper Board
General Cargo	8-Jul-89	GADO	1079	494	0		Ammonium Nitrate Emulite
General Cargo	25-Jul-89	PUERTO DE HANGA ROA	1940	1164	3	5	Minerals 1800 Tons
General Cargo	25-Sep-89	CALF SOUND	609	392	0		Cement Prefab. Buildings
General Cargo	19-Oct-89	DINA	1073	770	3	1	Paper Pulp
General Cargo	28-Oct-89	MURREE	18050	11940	0		Containers Methanol 205 Xylene
General Cargo	1-Nov-89	ARBON	1555	1439	0	2	
General Cargo	15-Nov-89	TYCHE	9984	6034	2		Logs 2,300
General Cargo	19-Nov-89	KAO HWA 3	5826	2990	2		
General Cargo	26-Nov-89	VIBEKE	785	299	0		Timber
General Cargo	7-Dec-89	JOHANNA B	5008	2806	0	16	Pig Iron
General Cargo	8-Dec-89	CAPITAINE TORRES	8769	6444	0	23	Machinery Containers
General Cargo	16-Dec-89	ARKLOW VICTOR	4250	2867	0	1	
General Cargo	20-Dec-89	NIAGA XXXIX	2968	1599	0		Asphalt 15,864 Drums
General Cargo	24-Dec-89	TOPOLOVENI	4737	3531	1	13	Steel 2,722 Tonnes
General Cargo	31-Dec-89	EVER LIGHT	1699	949	0		
General Cargo	6-Jan-90	KARA	5936	3278	0		Sawn Timber
General Cargo	11-Jan-90	IRVING FOREST	8253	6982	0		Woodpulp Newsprint
General Cargo	25-Jan-90	HUA ZHU	5106	2490	5	1	Logs
General Cargo	30-Jan-90	MIGHTY RYO	7137	4425	0		Logs
General Cargo	12-Feb-90	SEA CARRIER	2700	1400	1	8	
General Cargo	12-Feb-90	BREITHORN	5509	3266	0		Grain
General Cargo	17-May-90	SUCCESS STAR	672	199	0		Logs
General Cargo	19-Jun-90	MARINE JOY	6051	2992	0		
General Cargo	10-Nov-90	TENJIN MARU	380	197	0		Logs
General Cargo	11-Nov-90	JIAN CHANG	7609	5581	2		
General Cargo	10-Dec-90	CTE ROCIO	2543	998	0		
General Cargo	28-Dec-90	JARITA	725	644	1		Paper

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
General Cargo	16-Feb-91	INDOBARUNA II	6147	4756	4	19	Steel Products
General Cargo	21-Feb-91	SEFEROGLU 1	3600	2255	0		Steel Rails
General Cargo	21-Feb-91	PACIFIC FRIEND	7244	4360	7	7	Logs
General Cargo	6-May-91	RITA M	1524	966	0		Waste Paper
General Cargo	18-Jun-91	AYDA I	830	395	0		
General Cargo	8-Jul-91	RUTH RIIS	1720	1167	0		Ammonium Nitrate Electric Detonators
General Cargo	30-Jul-91	BOSTON TRADER	429	199	0		Beer 100 Tons
General Cargo	21-Sep-91	MARINE FUTURE	5123	2491	0		Logs
General Cargo	27-Oct-91	CELTIC KIWI	1094	911	0		Cement 850 Tonnes
General Cargo	7-Nov-91	APOLLONIA FAITH	9127	5999	1	1	Containers
General Cargo	16-Nov-91	COSMOS No. 2	4841	2625	0		
General Cargo	24-Nov-91	MARTA	2100	1202	0		Potassium In Bulk
General Cargo	30-Nov-91	TAYYAR SENKAYA	550	386	0	4	Sand
General Cargo	7-Dec-91	SCAIENI	4620	3374	1	9	Ammonium Nitrate
General Cargo	8-Dec-91	GHIWA	630	398	2		
General Cargo	27-Dec-91	KATERINA	980	499	0		
General Cargo	9-Jan-92	DOOYANG SAPPHIRE	6519	3950	0	1	Logs
General Cargo	24-Feb-92	WALIE 8	1552	708	0		Cement 1,200 Tonnes
General Cargo	5-Mar-92	PEONY	11599	6732	0		Gypsum
General Cargo	14-Mar-92	GOLDEN CAMIA	6103	3509	0		Logs General
General Cargo	24-Mar-92	ERI S	2878	1596	0		Fertiliser
General Cargo	26-Jun-92	ST. JOSEPH	1454	955	0		Cement
General Cargo	21-Sep-92	NEW OCEAN	7854	4678	0		Round Logs
General Cargo	2-Oct-92	HOLSTEN	2210	1859	0		Flour
General Cargo	23-Oct-92	RICHER	6076	4022	3	1	Cement
General Cargo	25-Oct-92	NORDFRAKT	1584	1599	0		Lead Concentrates
General Cargo	24-Nov-92	SHOSEN MARU No. 8	250	117	0	6	Fish
General Cargo	24-Nov-92	CHARM	4240	3133	3	5	Wire Rods
General Cargo	25-Nov-92	GEORGIA K	3844	2144	0		Iron Rods
General Cargo	1-Dec-92	SENG HING	1920	1596	0	1	Timber Products
General Cargo	4-Dec-92	CHUNG HO	4702	2849	0		Containers Bales Of Paper
General Cargo	18-Dec-92	SIAU	7052	3827	0		Steel Bars 3,000 T Plywood (In Bulk)

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
General Cargo	15-Jan-93	ACAMAR	5970	3146	9	12	Kaolinic Clay
General Cargo	21-Jan-93	NUSA MAS	1080	808	0		Cement, Bagged 450 T
General Cargo	23-Jan-93	GATEWAY	1090	499	0		Bitumen In Drums
General Cargo	23-Jan-93	ADI PERTIWI	6275	3718	0		
General Cargo	28-Jan-93	MARINE HAWK	5160	2493	3	2	Logs
General Cargo	30-Jan-93	NUPEN	371	199	0	1	
General Cargo	3-Feb-93	PROSPERITY	19052	10988	4	1	Fertiliser
General Cargo	15-Feb-93	SUN DANCER	2012	911	0		
General Cargo	21-Feb-93	NORDQUEEN	1472	499	0		Grain
General Cargo	13-Mar-93	FANTASTICO	1778	986	3	4	Fertiliser
General Cargo	24-Mar-93	XIAN REN	4097	2847	17	12	Iron Scrap
General Cargo	12-Apr-93	VISHVA MOHINI	13715	10092	12	21	Steel
General Cargo	10-Jun-93	PALMA	13920	7902	0		General
General Cargo	17-Jun-93	TALENT	3326	2276	3	14	Pulses 2,900 Tons
General Cargo	26-Jun-93	ATON	6791	4511	0		Ammonium Phosphate
General Cargo	1-Jul-93	ZAM ZAM	2205	1588	0		
General Cargo	2-Aug-93	CHALLENGE	15379	8754	1	2	Sugar Soap Rice
General Cargo	21-Aug-93	TAVEECHAI MARINE	4044	2722	0		Timber
General Cargo	12-Sep-93	MIRIAM	2550	1374	0		Wheat
General Cargo	17-Sep-93	POLESSK	11350	7192	1	28	Steel Pipes
General Cargo	19-Sep-93	AEGEO STAR	718	492	2		Plastics
General Cargo	1-Oct-93	SEABEC	864	499	0		Containers
General Cargo	4-Oct-93	EASTERN GLORY	4503	3046	0	9	
General Cargo	10-Oct-93	DJARFOGO	345	199	0		General Cargo
General Cargo	1-Nov-93	ANTONIOS	864	492	0		Corn
General Cargo	3-Nov-93	AMAL	2959	1585	0	8	
General Cargo	9-Nov-93	CHUL YANG	945	490	3	1	Oranges
General Cargo	20-Nov-93	SUCCESS 1	5139	2832	0	1	Timber
General Cargo	27-Nov-93	DASA TUJUH	7365	4611	3	5	Logs
General Cargo	10-Dec-93	SOUTHERN GLORY	3203	2427	0		General Sawn Timber
General Cargo	4-Feb-94	LEO	1000	486	0		
General Cargo	5-Mar-94	FALTICENI	4795	3531	0	4	Ammonium Nitrate

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
General Cargo	4-Apr-94	ELATMA	2100	1652	0		Ammonium Nitrate
General Cargo	2-Jul-94	KOTA SILAT IX	955	1159	0		General
General Cargo	12-Jul-94	KONSTANTIN ZANKOV	7700	6459	0		Pyrite Ore
General Cargo	11-Aug-94	SALEM TWELVE	15317	9283	0	4	
General Cargo	22-Aug-94	BERKAH	1168	496	2	5	
General Cargo	19-Oct-94	DANICA BLACK	960	997	0		Bagged Fertiliser
General Cargo	21-Oct-94	SYRVE	4375	3188	5	6	Cement
General Cargo	1-Nov-94	MARIYA	1652	1652	0		Timber
General Cargo	20-Nov-94	MAGED H	1264	399	0	1	Salt (In Bulk)
General Cargo	6-Dec-94	SHELBY STAR	2733	1585	0	2	Gypsum
General Cargo	9-Dec-94	SALVADOR ALLENDE	12007	10954	0	29	Rice
General Cargo	21-Dec-94	FRANCIA EXPRESS	3089	1260	0		
General Cargo	1-Jan-95	LINITO	1179	419	0		Marble
General Cargo	29-Jan-95	JIANG YONG GUAN	5593	4107	0	5	Iron Pyrites (5087t)
General Cargo	1-Feb-95	SANG THAI GALAXY	7192	4359	0	20	Cement Clinker
General Cargo	5-Feb-95	SUN RIVER II	11785	7341	11	3	Logs (11,000 Cm)
General Cargo	13-Mar-95	PELHUNTER	6138	4345	7	5	Containers
General Cargo	27-Mar-95	BISMI	1876	1104	0		General Onions
General Cargo	13-Apr-95	ANG LO	9750	7253	0		Cement
General Cargo	26-Jun-95	LINK STAR	10187	6241	0	23	Steel Products 9700t
General Cargo	17-Jul-95	PYRAMIDS	15807	9359	0		Steel Coils
General Cargo	19-Jul-95	ANNA II	1067	499	0		Bagged Cement
General Cargo	25-Jul-95	SUN SHINE 1	4311	3234	0	3	Palm Oil
General Cargo	3-Nov-95	MARIA I	2874	1808	1	7	Stones 2,507 Tonnes
General Cargo	7-Nov-95	CORALINE	6142	4351	0		Containers (139)
General Cargo	13-Nov-95	SANG THAI SILVER	5840	3086	0		
General Cargo	14-Nov-95	GIGEK	4955	3132	0		Containers (Maize)
General Cargo	12-Dec-95	BUREYA	1280	1449	0		Rice (100t)
General Cargo	25-Dec-95	ANDHIKA WANASATYA	6654	3890	1	13	Logs
General Cargo	27-Dec-95	YAYASAN ENAM	8027	5106	0		Logs
General Cargo	4-Jan-96	BIANKA PRIMA	398	398	0	9	Passengers Plywood

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
General Cargo	6-Jan-96	COVASNA	4620	3374	0		Steel Pipes
General Cargo	7-Jan-96	KATHLEEN D	1516	843	0	8	Sulphate
General Cargo	5-Feb-96	RICO	11603	7094	0		Cement Clinker
General Cargo	11-Feb-96	HELENA JAYNE	481	382	0		
General Cargo	20-Feb-96	OCEAN RUBY	5145	2818	0	2	Logs
General Cargo	27-Feb-96	YOM BUN JIN	9950	6676	2	33	Anthracite
General Cargo	27-Mar-96	DAVID JUNIOR	1000	998	0	6	Cement
General Cargo	2-May-96	DUMAGUETE DOLPHIN	500	224	0	5	Fertiliser Corn
General Cargo	19-Jul-96	AMELIE	830	497	0		
General Cargo	23-Jul-96	SUNDANCE	17524	12499	0	2	Bulk Potash
General Cargo	25-Jul-96	FUGA I	695	346	1		Bagged Cement Container
General Cargo	13-Sep-96	PRAGA	330	197	0	3	Food Supplies Car
General Cargo	13-Nov-96	CORDIGLIERA	16525	12025	5	24	Steel Paper
General Cargo	15-Nov-96	PULSAR	1746	1501	2		Lumber
General Cargo	16-Nov-96	BLUE SKY	6470	4375	0		
General Cargo	22-Nov-96	HALSTENBEK	936	564	1		Grain
General Cargo	24-Nov-96	PROMEX AMAN	7851	4685	0		Logs; 6,000 Tons
General Cargo	24-Dec-96	BERRACK S	1073	399	0		
General Cargo	8-Jan-97	ONUR K	1800	989	4	1	Zinc/Lead Concentrat
General Cargo	8-Jan-97	SUN RICHIE 3	11598	6799	0		
General Cargo	30-Jan-97	AHMET AKDENIZ	824	498	1	2	Flour, 750t
General Cargo	9-Mar-97	DISARFELL	8020	5967	2		Containers
General Cargo	13-Jun-97	CALARASI	4800	3493	0	1	Fishmeal
General Cargo	15-Jun-97	GANDASULI	340	331	0	4	Fertiliser General
General Cargo	19-Jun-97	ARCADIA PRIDE	13761	9707	6	18	Sulphur
General Cargo	31-Jul-97	SEA EMPRESS	4410	3011	0		Sulphur; 4200 Tonnes
General Cargo	20-Oct-97	BLACK SEA T	10157	6390	0	1	Rape Seed Wheat
General Cargo	19-Dec-97	ANJANA	5662	3676	0		Stone
General Cargo	17-Jan-98	AGIOS PANTELEIMON	3018	1847	2	5	Ammonium Sulphate
General Cargo	2-Feb-98	DELFIN DEL MEDITERRANEO	6332	4614	1		Containers
General Cargo	5-Feb-98	ANTELOPE	2106	1165	4	1	Aluminium Coil

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
General Cargo	14-Feb-98	BEG	1090	1079	0	5	
General Cargo	25-Feb-98	SUNDARI	850	566	0		Coal; 700 T
General Cargo	27-Feb-98	ULSUND	2106	1572	2	5	Aluminium
General Cargo	10-Apr-98	DON MARIO	4394	2850	0	3	Steel
General Cargo	15-Apr-98	LYN	1133	902	0		Herrings In Drums
General Cargo	13-Jun-98	ALIMAD	4064	2706	0		Bagged Cement
General Cargo	28-Jun-98	WORLD PEACE	14711	9152	0		Marble Chrome Ore
General Cargo	16-Oct-98	ASTER	3080	1821	3	3	Phosphor
General Cargo	19-Oct-98	CANTIK	9540	5656	0	2	
General Cargo	24-Nov-98	KALIMANTAN EXPRESS	4399	3082	0		Peas
General Cargo	15-Dec-98	MARIA MADIA	15177	9176	0		
General Cargo	9-Jan-99	DUBA	430	296	0		
General Cargo	16-Jan-99	CAROLINES	10010	6209	0		Silica Sand, 6,000 T
General Cargo	5-Feb-99	PETIT FOLMER	570	415	2	2	Fertiliser In Bulk
General Cargo	16-Mar-99	CORE No. 8	4017	3253	0		Ore
General Cargo	8-May-99	PENGIBU	3400	2340	18	8	Cement In Bags
General Cargo	8-Jul-99	LIFTMAR	2896	2021	0		Copper & Tin Oxide
General Cargo	9-Jul-99	ARKTIS QUEEN	2676	1829	0	5	Timber
General Cargo	20-Oct-99	HENRY NAVIGATOR	13600	11033	0		Minerals
General Cargo	29-Oct-99	DUBAI OASIS	8230	6212	0		Steel Coil
General Cargo	5-Nov-99	DOLLY	366	289	0		Bitumen
General Cargo	9-Nov-99	ALICAN DEVAL	1812	982	0	7	Ore
General Cargo	15-Dec-99	VIOLET OCEAN	5117	3009	0		Logs
General Cargo	16-Dec-99	CAPRICORN	3173	1767	1		Wood
General Cargo	31-Dec-99	SAMARET JAMA	906	630	0		
General Cargo	26-Jan-00	RUI DA	7529	4942	0		Logs
General Cargo	27-Jan-00	YIAW YANG	8813	5577	0		
General Cargo	21-Feb-00	LINA STAR	1170	672	0		Soda Ash
General Cargo	23-Feb-00	VESTKYST	415	276	0		Sand
General Cargo	4-Mar-00	IUGO	8749	5934	0		Iron Ore Residue
General Cargo	15-May-00	SKY 1	1165	1069	0		Saloon Cars Stainless Steel

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
General Cargo	1-Aug-00	VALEA ASRE	11597	6441	0	2	
General Cargo	17-Aug-00	BANGLUANG	6042	3908	0	11	Timber
General Cargo	5-Nov-00	RYAZAN	5657	4937	0		Foodstuff
General Cargo	10-Nov-00	ELENA	2893	2457	0		General/Containers
General Cargo	2-Dec-00	SKY PRIMA	3052	1998	0		General/Containers
General Cargo	14-Dec-00	STEINFALK	396	212	0	3	Sand
General Cargo	23-Dec-00	ANITA	752	500	1	8	General Cars Tyres On Deck
General Cargo	7-Jan-01	WHITE KOOWA	4638	3561	8	1	Nickle Ore
General Cargo	24-Jan-01	STAR ADMIRAL	17850	15893	0		
General Cargo	28-Jan-01	HOLLY TRADER	1894	1518	0		Fertiliser
General Cargo	18-Feb-01	FERNANDINA	5008	2806	0		Fertiliser
General Cargo	8-Mar-01	PAMELA DREAM	6475	3946	6	2	Timber
General Cargo	20-Jun-01	GOSELLA	5052	3156	0	1	Timber
General Cargo	9-Sep-01	WINDFJORD	2060	1678	0		Timber
General Cargo	20-Oct-01	LAM SON-02	200	166	0		Genearl
General Cargo	2-Nov-01	EM EL NOUR	1074	842	0		Wood
General Cargo	8-Nov-01	HO FENG No. 8	9588	5801	0		Logs
General Cargo	17-Nov-01	SAMRA	1734	961	6		Oil
General Cargo	7-Dec-01	MEDTRADER	3060	2068	0	1	Steel
General Cargo	9-Dec-01	KALKAVAN	2123	1087	0		Iron Ore
General Cargo	10-Dec-01	LADY AMAR	11899	6986	0	1	Iron Ore
General Cargo	11-Feb-02	TRIUMPH KAOHSIUNG	6278	3986	6	1	Steel Coils
General Cargo	11-Mar-02	CAMADAN	3048	1855	0		Fertiliser
General Cargo	5-Apr-02	EBN HAWKEL	9420	7533	10	15	Flour
General Cargo	20-May-02	FAIRTECH I	1000	515	0		Cement Clinker
General Cargo	9-Jun-02	BELLA 1	6207	3964	0		Containers Vehicles
General Cargo	18-Aug-02	IREMIA	7085	5716	0		Sugar, Rice Steel Bars
General Cargo	22-Oct-02	GEORGIOS S	7880	6171	0		Soil
General Cargo	26-Oct-02	ASSEBURG	2890	1939	0		
General Cargo	6-Nov-02	DNEPROVETS-6	1322	1550	0	2	Potash Fertiliser
General Cargo	5-Jan-03	ALEKSEY VIKHAREV	3135	2478	0		16500 Logs
General Cargo	11-Jan-03	KHADIJEH	1968	1205	0		

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
General Cargo	27-Jan-03	HORNET	3209	2095	0		Plywood Timber
General Cargo	30-Jan-03	COUGAR	6068	4163	0		Kaolin
General Cargo	3-Feb-03	STRELETS	4540	3390	9	2	
General Cargo	18-Feb-03	KARIN CAT	1680	1501	0		Heavy Equipment
General Cargo	21-Feb-03	PENDOLA	6503	4252	0	4	2000 Logs
General Cargo	25-Feb-03	KEMAL OKAN	1137	690	0		Gypsum
General Cargo	3-Apr-03	ALASKA	627	397	0	5	Citrus Fruit
General Cargo	21-May-03	BEHZAT SENKAYA	1172	687	0		
General Cargo	24-Jun-03	OCEAN PIONEER	2893	1516	0		2300 Tons Of Wheat
General Cargo	12-Aug-03	YU JIA	15210	9182	0		Chrome Ore
General Cargo	1-Oct-03	MARTINIKA	3001	1886	0		3000 Tonnes Iron
General Cargo	15-Oct-03	ENINA	1585	996	0		1020 Tonnes Cement
General Cargo	26-Nov-03	MY SON	400	376	0		460 Tonnes Tapioca
General Cargo	23-Jan-04	QUEEN	6243	3970	0		
General Cargo	23-Jan-04	KEPHI	8355	5315	3	12	8000 Tonnes Cement
General Cargo	7-Feb-04	DURY	7054	5552	12	6	6,000 Tonnes Steel
General Cargo	13-Apr-04	GENIUS STAR VI	5107	3005	0	2	6000 Mt Logs
General Cargo	24-May-04	FAMILY ISLAND EXPRESS	493	526	1		Cement Blocks
General Cargo	9-Jul-04	MINI MOON	3020	1881	4	6	2,700 Tons Urea
General Cargo	16-Jul-04	AMAMI	980	718	0	12	2 Passengers Wheat, Rice Sugar
General Cargo	27-Jul-04	SUNSHINE KING	450	482	0		2,000 Bgs Fertilizer
General Cargo	11-Sep-04	OSTRIA	1847	1427	0		Marble
General Cargo	2-Nov-04	WEST	1847	1427	16	9	1,078 Tons Timber
General Cargo	2-Nov-04	AROS	5017	2811	1	7	4,400 Tons Coal Timber
General Cargo	12-Nov-04	LADY GRACE	719	478	0	1	Cement
General Cargo	2-Jan-05	GLOBAL ISLAND	2909	1998	0	2	
General Cargo	4-Jan-05	ALEXANDROS	3063	1623	0	12	2,800 T. Blk Potash
General Cargo	16-Jan-05	FIANDARA	965	863	0		Timber Steel
General Cargo	17-Jan-05	LADY O	1968	1653	2	6	732 Mt Steel 1 Passenger
General Cargo	20-Jan-05	PIONEER NAYA	4605	2826	6	8	4150 Tons Iron
General Cargo	2-Feb-05	VIGLA	2015	1153	6	1	Salt
General Cargo	14-Feb-05	SEA REY	1559	1059	0	2	Containers

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
General Cargo	8-Oct-05	MIDAS 1	1594	1300	0		Steel
General Cargo	22-Nov-05	AN JIN	5118	3124	0	13	Steel Ingots Cast Iron
General Cargo	22-Dec-05	OCEAN STAR	399	399	0		
General Cargo	8-Jan-06	PAINKIRA	203	159	0		Food Automobiles Cattle
General Cargo	23-Jan-06	A. AKIF	4600	3269	2		Ballast
General Cargo	1980-04-00	THEOFILACTOS	420	302	0		Cigarettes
General Cargo	1980-12-00	OMAR	561	369	0		
General Cargo	1988-00-00	WILLAURIE	376	244	0		
General Cargo Barge	2-Mar-04	BULK	14002	9066	0		Coal
General Cargo, Sailing	12-Mar-92	SOLVANG III	180	149	0		Wooden Pallets
General Cargo/Container Ca.	16-Apr-94	TABASCO	22229	16087	0		Containers
General Cargo/Tanker	23-Jan-01	ILES DU PONANT	320	227	0	4	
General Dry Cgo/Container Ship	14-Feb-79	FRANCOIS VIELJEUX	16257	12458	11	12	Coffee Tea Copper And Zinc
General Dry Cgo/Container Ship	26-Nov-81	ELMA TRES	10497	7470	1	22	Containers
General Dry Cgo/Container Ship	20-Oct-86	CARIBE ENTERPRISE	12426	11447	0		
Roro Cargo	12-Nov-77	HERO	3692	3468	1		
Roro Cargo	28-Dec-80	CHERCHELL	1737	1062	0		General
Roro Cargo	15-Feb-82	MEKHANIK TARASOV	5306	4262	20	12	Newsprint 2,500 Tons
Roro Cargo	14-Jan-87	AMIRA	5675	3710	0		Cars
Roro Cargo	30-Mar-87	AL HOCEIMA	2743	1576	0		Trucks Containers
Roro Cargo	28-Feb-88	VINCA GORTHON	10945	18773	0		Paper Wood Pulp Trailers
Roro Cargo	13-Sep-88	RA	2489	1333	0		Beer
Roro Cargo	9-Dec-88	EL CARRIER I	2993	1508	0		Rolling Eqpt.
Roro Cargo	7-Apr-90	EAL DIAMOND	13971	19689	0		Coffee Cocoa Containers
Roro Cargo	27-Feb-93	ISLA DE LA GOMERA	1438	1123	1	4	Horses Containers
Roro Cargo	6-Sep-01	LYNN	1155	1542	0		Copper Sheets
Roro Cargo	22-Jan-03	WHITE SEAL	5923	7037	0		
Roro Cargo	16-Jun-04	DORSET	3300	2084	0		
Ore Carrier	29-Oct-87	TOPKAPI-S	61940	36900	5	11	Iron Ore 59,000 Tons
Ore Carrier	13-Nov-91	SONATA	79681	25597	0		Iron Ore Pellets
Ore Carrier	1-Jan-94	MARIKA	169147	81262	0	36	Iron Ore

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
Ore Carrier	3-Sep-94	IRON ANTONIS	93356	48756	0	24	Iron Ore
Ore/Oil Carrier	25-Jan-81	DEIFOVOS	70341	29689	5	4	Iron Ore
Ore/Oil Carrier	22-Jan-85	HOPE STAR	116654	66593	0		Iron Ore
Refrigerated Cargo	31-Oct-78	GOLAR BORG	7717	4892	0	4	Potatoes
Refrigerated Cargo	2-Mar-80	ZEUS	701	490	2	4	
Refrigerated Cargo	13-Dec-81	BONITA	9143	6682	1		Fertilizer 3,300 T
Refrigerated Cargo	13-Nov-86	NISSOS SKOPELOS	9186	6691	0		Potatoes
Refrigerated Cargo	16-Nov-87	FRIO	694	300	0		General
Refrigerated Cargo	20-Nov-94	SAN GEORGIO REEFER	944	487	0		
Refrigerated Cargo	23-Oct-97	VANESSA	5265	3955	4	1	Fertiliser; 3,200 T
Refrigerated Cargo	7-Feb-05	JOKULFELL	3200	2469	6		1,978t. Steel Containers
Refrigerated Cargo	20-Jan-06	GUCLU 4	2170	1216	1		2,050 Tons Marble
Aggregates Carrier	17-Jun-80	SAM JIN NO. 7	1279	227	0		Sand 800 Tons
Aggregates Carrier	2-Feb-83	FUKUHO MARU NO. 3	1500	495	0		Sand, 730 Tons
Aggregates Carrier	14-Mar-86	MEIWA MARU NO. 2	250	199	1	2	Gravel, 350 Tons
Aggregates Carrier	15-May-86	HATANO MARU	1304	498	0		Sand
Aggregates Carrier	30-Sep-86	KOSEI MARU No. 5	450	199	0		Stone 200 Cu M
Aggregates Carrier	1-Apr-88	UNISON III	1665	498	0	1	
Aggregates Carrier	10-Dec-88	HOEI MARU No. 15	450	199	0		
Aggregates Carrier	23-Dec-92	NAKAFUKU MARU	500	290	1	1	Gravel
Aggregates Carrier	2-Jun-93	SEISHO MARU No. 18	1100	949	0		
Aggregates Carrier	24-Jun-95	NIVIA	647	793	0		Stone Blocks
Deck-Cargo Ship	8-Jul-05	SPP-13	125	193	0	4	20 Containers
Dredger	15-Sep-78	SAND TRANS	1077	493	0		Stone
Dredger/Sand Carrier	2-Nov-88	HOLMI	315	236	0		Gravel
Dredger/Sand Carrier	5-Dec-88	BOWSPRITE	2093	1503	2	2	Sand & Gravel
Dredger/Sand Carrier	11-Jan-99	KAE CHUCK JIN	6780	4160	6		Sand
TOTAL	**626**		**2922772**	**1813289**	**740**	**1627**	

Appendix IX: Data for Passengers Ships/ RoRo/ Containerships Loss

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
Roro Cargo/Ferry	7-Sep-66	SKAGERAK	2726	2726	1	0	Passengers Railway Carriages 7. Cars 30
Roro Cargo/Ferry	17-Apr-80	MAURITIUS II	2650	2522	0	0	Steel
Roro Cargo/Ferry	30-Nov-87	GULF KANAYAK	5010	5010	0	0	
Roro Cargo/Ferry	28-Dec-89	ZAKYNTHOS	1559	1559	1	0	Vehicles Passengers
Roro Cargo/Ferry	12-Jul-90	TRADER	215	462	0	0	Passengers Containers Beer
Roro Cargo/Ferry	27-Oct-94	VISTA	165	165	0	0	
Roro Cargo/Ferry	15-Aug-97	KALIBO STAR	656	485	12	43	Passengers
Roro Cargo/Ferry	8-Jul-02	SAN MIGUEL DE ILIJAN	341	341	0	0	
Roro Cargo/Ferry	7-Sep-03	WIMALA DHARMA	75	644	6	5	30 Vehicles 168 Passengers
Roro Cargo/Ferry	9-Mar-04	SAM-SON	650	759	0	95	78 Passengers
Roro Cargo/Ferry	1-Feb-06	CITRA MANDALA BAKTI	321	321	1	47	Passengers
Passenger	6-Jun-80	SAUDI-FILIPINAS	8894	32360	0	0	
Passenger	15-Jan-81	GOLDEN PRINCESS	2883	2883	0	0	
Passenger	4-Aug-91	OCEANOS	6090	7554	0	0	Passengers
Passenger	17-Nov-97	CONSTITUTION	7222	29638	0	0	
Passenger	17-Dec-00	SEABREEZE I	5671	21010	0	0	34 Passengers
Passenger	26-Jan-01	PAMYAT MERKURIYA	270	790	14	5	Passengers
Passenger	6-Jul-01	SEA	3885	23292	0	0	
Passenger/General Cargo	8-Nov-78	GLACIER QUEEN	936	1833	0	0	
Passenger/General Cargo	11-Feb-79	TORRES	1183	4208	0	0	
Passenger/General Cargo	26-Mar-80	CITY OF ATHENS	2174	9126	0	0	
Passenger/General Cargo/Ferry	22-Oct-83	SUNNFJORD II	934	934	0	0	
Passenger/Roro Cargo	2-Jun-80	ZENOBIA	10000	12000	0	0	Trailer Trucks Passengers
Passenger/Roro Cargo	14-Jan-93	JAN HEWELIUSZ	2035	3015	40	15	Passengers Lorries Railway Carriages
Passenger/Roro Cargo	22-Oct-02	MERCURY-2	3950	11450	1	43	Passengers Oil Containers
Passenger/Roro Cargo/Ferry	13-Apr-86	ISLA DE CUBAGUA	1006	3733	0	0	
Passenger/Roro Cargo/Ferry	28-Sep-94	ESTONIA	2935	21794	94	758	Passengers Vehicles
Passenger/Roro Cargo/Ferry	18-Sep-98	PRINCESS OF THE ORIENT	3110	13614	64	86	Passengers Vehicles; 15 Containers; 66

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
Passenger/Roro Cargo/Ferry	19-Apr-00	FAGR	800	5993	0	0	
Passenger/Roro Cargo/Ferry	26-Sep-02	LE JOOLA	500	2087	350	620	Passengers
Passenger/Roro Cargo/Ferry	29-Oct-03	AL HUDA	3373	3691	0	0	
Passenger/Roro Cargo/Ferry	22-Mar-06	QUEEN OF THE NORTH	1205	8889	2	0	102 Persons
Ferry	16-Sep-73	ATHENS	254	586	1	2	
Ferry	4-Jan-79	AMALPHIS PRIMA	324	324	0	0	
Ferry	24-Aug-83	TACHIBANA	58	137	0	0	
Ferry	13-Nov-98	RAHMAT BUHARI	150	413	0	40	Passengers
Ferry	31-Mar-99	USIWE KUPE	77	120	0	0	Passengers
Ferry	7-Jul-05	DIGUL	150	224	74	100	Passengers Vehicles/Cement Heavy Equipment
Ferry/General Cargo	6-Jan-85	ASIA SINGAPORE	260	719	1	20	Passengers
TOTAL	**39**		**84697**	**237411**	**662**	**1879**	

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
Container Ship	9-Jan-82	EASTERN KIN	9246	11400	0		Scrap Iron
Container Ship	13-Feb-87	HANJIN INCHEON	18846	17676	1	22	Containers
Container Ship	26-Dec-87	ISLAND QUEEN	3298	2824	0		Timber
Container Ship	28-Dec-88	LLOYD BERMUDA	1703	824	2	6	Containers
Container Ship	19-Nov-89	DESPO	2175	1456	0	1	Tomato Juice
Container Ship	31-Jan-92	TAVRIYA-7	1706	1408	3	3	Metal Pipes
Container Ship	19-Feb-96	GU CHENG	13058	9683	0	30	Containers
Container Ship	10-Dec-02	MATTEN	6850	5552	0		Containers
TOTAL	**8**		**56882**	**50823**	**6**	**62**	

Appendix X: Data For Tankers

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
Tanker	13-Jun-68	WORLD GLORY	47179	28323	4	22	Crude Oil
Tanker	5-Nov-69	KEO	30487	15797	9	27	Fuel Oil
Tanker	25-Nov-69	PACOCEAN	30498	17328	1	2	Crude Oil
Tanker	6-Jan-70	SOFIA P	18919	12113	7		Avgas Turbo Fuel
Tanker	14-Jan-70	ALBACRUZ	20693	12607	0		Crude Oil
Tanker	6-Oct-70	ANASTASIA J.L.	18797	12525	0		Crude Oil
Tanker	26-Dec-70	RAGNY	17588	11079	1	5	Auto Diesel Heating Oil
Tanker	26-Dec-70	CHRYSSI	31717	19183	0	21	Crude Oil
Tanker	27-Mar-71	TEXACO OKLAHOMA	35635	20084	0	31	Fuel Oil No.6 Grade
Tanker	6-Jul-71	ALKIS	20047	11971	0		Crude Oil
Tanker	2-Sep-71	AARON	16470	10518	0	2	Mollasses Tar, Acid,Oil,Gas
Tanker	5-Mar-72	SAN NICOLAS	17090	10255	0	28	Molasses
Tanker	19-Feb-73	NELSON	21073	12784	0		Fuel Oil
Tanker	10-Jan-75	BRITISH AMBASSADOR	45672	27114	0		Crude Oil
Tanker	4-Apr-75	SPARTAN LADY	21056	12689	1		Fuel Oil
Tanker	14-Oct-76	BOHLEN	11570	7644	16	9	Crude Oil
Tanker	27-May-77	CARIBBEAN SEA	31153	18372	0		Crude Oil
Tanker	28-Jun-79	AVILES	26245	15409	3	8	Jet Fuel 22500 Tons
Tanker	1-Oct-79	HAKUSHIN MARU NO. 5	541	299	0		
Tanker	7-Mar-80	TANIO	27700	18048	6	2	Heavy Fuel Oil
Tanker	13-Feb-81	BOA NOVA	603	424	0	8	
Tanker	17-Feb-81	WITSUPPLY	2235	1335	0		
Tanker	19-Feb-81	RONE	254	149	0		Oil
Tanker	19-Feb-81	SEFIR	600	449	0		Diesel Oil Light Oil
Tanker	12-Feb-82	VICTORY	21032	12487	1	14	Molasses
Tanker	13-May-82	FUKUYOSHI MARU	1660	946	0		Oil
Tanker	9-Sep-82	MAE PING	660	558	0		
Tanker	30-Nov-82	KASHIMA MARU	700	413	0	3	Hydrochloric Acid
Tanker	26-Jun-84	TESUBU II	21446	13154	0	26	Molasses
Tanker	16-Aug-86	MAYSUN	2093	1202	0	7	Bunker Fuel 14000brl
Tanker	25-Dec-86	STAINLESS TRADER	3475	1599	3	5	Sulphuric Acid

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
Tanker	28-Jun-87	ELENI S	2388	1399	0		Deisel Oil-1800tons
Tanker	15-Sep-87	BOREA	3095	1599	0		
Tanker	3-Feb-88	TENRYU MARU No. 5	1000	494	0		Acetic Acid
Tanker	24-Feb-88	KYUNG SHIN	2299	995	0		Bunker C, 2650 K/L
Tanker	9-Dec-88	KASUGA MARU NO. 1	1204	480	0		Bunker C Oil
Tanker	18-Jan-89	KAMRAN	488	469	0		
Tanker	14-Feb-89	DELIMA 120	2476	996	0		Marine Oil 270t
Tanker	6-Jan-91	KIMYA	1876	985	4	6	Sunflower Oil 1500 T
Tanker	1-Feb-91	ALESSANDRO PRIMO	3994	2506	0		Dichlorethane Acrylonitrile
Tanker	16-Apr-92	KATINA P	69992	30890	0		Heavy Oil 66,700t
Tanker	14-Nov-92	MARVIN 1	1214	693	0		Bitumen 1,000 T
Tanker	9-Dec-93	GRAPE ONE	3439	1599	0		Xylene 3000t
Tanker	23-Jul-94	PALAWAN ISLAND	7535	9361	0		Fuel Oil Lumber
Tanker	14-Jan-95	MAHAL	350	178	0	2	Molasses
Tanker	26-Oct-95	ANNIE No. 1	1096	751	0		
Tanker	14-Jan-96	RECOVERY III	1118	950	0		Slops
Tanker	9-Feb-96	KIRA	8264	4998	0	18	Phosphoric Acid
Tanker	2-Jan-97	NAKHODKA	20471	13157	0	1	Heavy Fuel Oil
Tanker	9-Nov-99	YOUNG CHEMI	1047	735	1	2	Chloraform
Tanker	11-Dec-99	ERIKA	37283	19666	0		Heavy Fuel Oil
Tanker	30-Oct-00	IEVOLI SUN	7308	4189	0		Styrene Isopropyl Al
Tanker	20-Mar-01	BALU	9981	5795	0		Sulphuric Acid
Tanker	13-Nov-02	PRESTIGE	81564	42820	0		Heavy Fuel Oil
Tanker	16-Feb-04	YUG	1634	950	0	6	Disposed Oil Product
Tanker	10-May-05	BIG SEA 5	1750	699	0		
Tanker	24-Mar-06	ORION	1039	1223	0	3	806 T. Fuel Oil
Tender	5-Oct-84	ALTA MAR I	0	1409	0		
Liquefied Gas Tanker	4-Jan-79	MILLI	1118	1113	0		Butane
Liquefied Gas Tanker	8-Apr-79	NIKKO MARU NO. 51	3499	2160	0		Pebbles, 3000 Tons
Liquefied Gas Tanker	13-Oct-80	GAZ EAST	1602	1703	0		Butane Gas Gasoil
Liquefied Gas Tanker	12-Dec-82	BANDIM	1849	1843	0		Butane Propane

ShipType	Casualty Date	NAME	DWT	GT	Killed	Missing	CARGO
Liquefied Gas Tanker	14-Nov-88	ELPINA III	563	593	1	2	Lpg
Liquefied Gas Tanker	5-Jan-94	RED STAR	4768	5706	0		Butane Gas
Liquefied Gas Tanker	10-Dec-95	BILLY FOUR	850	497	1		Lpg
Liquefied Gas Tanker	25-Aug-96	PACK ONE	850	699	0		Liquefied Petro Gas
Liquefied Gas Tanker	22-Nov-97	APANCHANIT No. 5	1999	1684	0		Vinyl Chloride
Liquefied Gas Tanker	14-Nov-05	TONG CHENG 818	1135	998	0	0	
TOTAL	**68**		**837026**	**493840**	**59**	**260**	

Appendix XI: Calculation Of Costs for Several Types of Ships

Cost of Human Life	$CL := 2337034$

Bulkcarriers

Total Number of Killed/Missing	$N_{kil\_b} := 797$
Total Number of Accidents	$Nacc\_b := 75$
Second Hand Price in US$/Ton	$Price_{s\_h\_b} := 378.51$
Cargo average price in US$/Ton	$Price_{cargo\_b} := 1749.36$
Total Gross Tonnage lost	$GT_b := 1807729$
Total Deadweight lost	$DWT_b := 3261035$

$$Cost_b := CL \cdot \frac{N_{kil\_b}}{Nacc\_b} + Price_{s\_h\_b} \cdot \frac{DWT_b}{Nacc\_b} + Price_{cargo\_b} \cdot \frac{GT_b}{Nacc\_b}$$

$$\boxed{Cost_b = 8.346 \times 10^{7}}$$

Tankers

Total Number of Killed/Missing	$N_{kil\_t} := 319$
Total Number of Accidents	$Nacc\_t := 68$
Second Hand Price in US$/Ton	$Price_{s\_h\_t} := 309.07$
Cargo average price in US$/Ton	$Price_{cargo\_t} := 595.05$
Cost of oil spills clean-up in US$/Ton	$Cost_o := 8300$
Total Gross Tonnage lost	$GT_t := 493840$
Total Deadweight lost	$DWT_t := 837026$

$$Cost_t := CL \cdot \frac{N_{kil\_t}}{Nacc\_t} + Price_{s\_h\_t} \cdot \frac{DWT_t}{Nacc\_t} + Cost_o \cdot \frac{0.5GT_t}{Nacc\_t} + Price_{cargo\_t} \cdot \frac{GT_t}{Nacc\_t}$$

$$\boxed{Cost_t = 4.923 \times 10^{7}}$$

Containerships

Total Number of Killed/Missing	$N_{kil\_c} := 68$
Total Number of Accidents	$N_{acc\_c} := 8$
Second Hand Price in US$/Ton	$Price_{s\_h\_c} := 378.51$
Cargo average price in US$/Ton	$Price_{cargo\_c} := 1749.36$
Total Gross Tonnage lost	$GT_c := 50823$
Total Deadweight lost	$DWT_c := 56882$

$$Cost_c := CL \cdot \frac{N_{kil\_c}}{N_{acc\_c}} + Price_{s\_h\_c} \cdot \frac{DWT_c}{N_{acc\_c}} + Price_{cargo\_b} \cdot \frac{GT_c}{N_{acc\_c}}$$

$$\boxed{Cost_c = 3.367 \times 10^{7}}$$

General Cargo

Total Number of Killed/Missing	$N_{kil\_g} := 2371$
Total Number of Accidents	$N_{acc\_g} := 626$
Second Hand Price in US$/Ton	$Price_{s\_h\_g} := 378.51$
Cargo average price in US$/Ton	$Price_{cargo\_g} := 1749.36$
Total Gross Tonnage lost	$GT_g := 1814262$
Total Deadweight lost	$DWT_g := 2923869$

$$Cost_g := CL \cdot \frac{N_{kil\_g}}{N_{acc\_g}} + Price_{s\_h\_g} \cdot \frac{DWT_g}{N_{acc\_g}} + Price_{cargo\_g} \cdot \frac{GT_g}{N_{acc\_g}}$$

$$\boxed{Cost_g = 1.569 \times 10^{7}}$$

Passenger Ships

Total Number of Killed/Missing	$N_{kil\_p} := 2541$
Total Number of Accidents	$Nacc\_p := 39$
Second Hand Price in US$/Ton	$Price_{s\_h\_p} := 378.51$
Total Deadweight lost	$DWT_p := 84697$

$$Cost_p := CL \cdot \frac{N_{kil\_p}}{Nacc\_p} + Price_{s\_h\_p} \cdot \frac{DWT_p}{Nacc\_p}$$

$$\boxed{Cost_p = 1.531 \times 10^{8}}$$