What is the GM_T? ...

And Why it is Important

Whitepaper 1401

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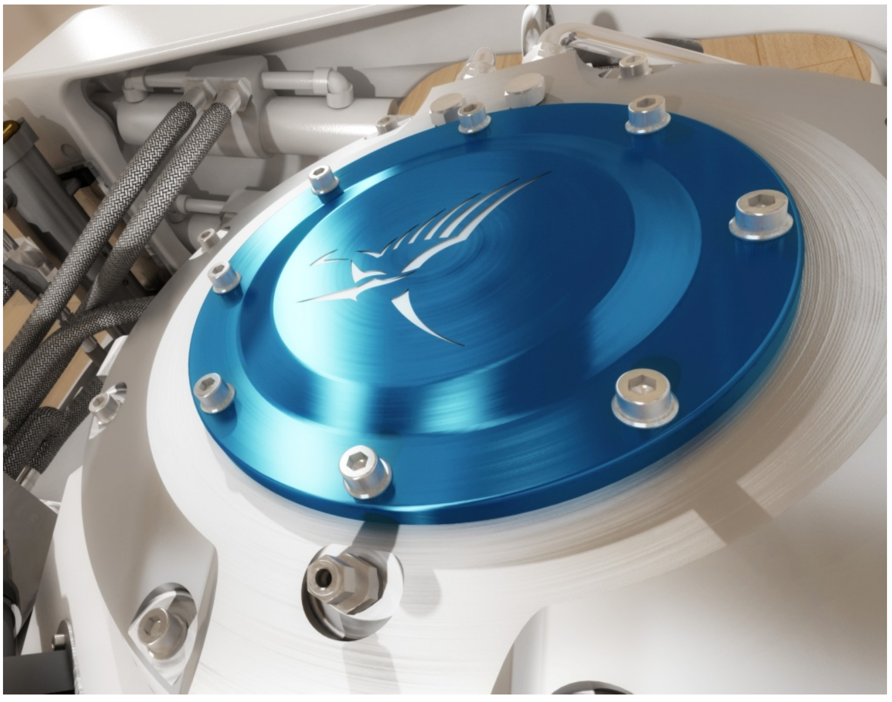

What is the GM_T ? …

And Why it is Important

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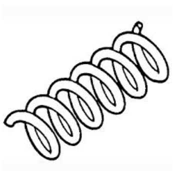
This article explains exactly what the mysterious GM_T is, and why it is such a critical number when discussing roll stabilization.

A Spring Stiffness / Roll Stiffness Analogy

Before we launch into what the GM_T is, allow me to present a brief analogy to help describe rolling ‘stiffness’ of yachts.

Forgetting waves for now, lets consider a yacht resting in calm water. We call this a static situation as is is not changing over time. The Stability Booklet on the bridge of your yacht discusses the ‘static’ stability of the yacht. The ‘static’ stabilty ignores the effect of waves.

Now, if you were magically able to heel your yacht over away from upright, and then you let it go, we know that it would roll back to it’s upright position (let’s hope so anyway). This is a bit like what happens when you stretch a spring…if you let it go, it returns to its natural relaxed length. The stiffness of a spring (K) is the ratio of the force applied to stretch the spring (F), and the amount the spring extends (X). This can be written as a mathematical equation as follows:



$$F = K \times X$$

Force = stiffness x extension

So a spring with high stiffness requires more force to stretch it by a certain amount.

In the same way the stiffness of a yacht hull (K) in the rolling axis is the ratio of the applied roll moment, or torque (RM), and the amount the yacht rolls in degrees (Θ). The rolling moment might for instance be applied by a heavy weight located near either deck side. This can be written as a mathematical equation as follows:

$$RM = K \times \Theta$$

Roll Moment = roll stiffness x roll angle

So a yacht with high stiffness requires a larger roll moment to produce a certain level of heel. This resistance to heeling on high stiffness yachts is the reason that stiff yachts are often described as having high static stability. A yacht with high roll stiffness will roll less as large weights (like fuel in the tanks, or large tenders) are moved around the yacht, leading to the common description of such a yacht as being highly stable.

For yachts (and other types of boat and ship), the roll stiffness is proportional to this thing called the GM_T (I will get to what exactly the GM_T is soon). So, the higher the GM_T, the higher the stiffness, and vice versa.

Now that this is understood, if we forget waves, we could be excused for thinking that a yacht with the highest stiffness possible, will provide us with the most stable platform for enjoying yachting... Unfortunately, as we are about to learn, high static stability often leads to high rolling motions in waves and lower comfort!

Some Naval Architecture

Flat Water - Static Stability (Nice in Theory)

Before we consider the real situation of a ychat operating in waves. We first consider the easier to discuss but unrealistic situation of flat water. The way a yacht heels in flat water is called it's 'static stability' by naval architects.

There are lots of strange letters and numbers in the Stability Booklet. The decription below will clarify the key letters and numbers in any discussion about rolling motion.

Consider a slice across the hull of the yacht near the middle (midships) as illustrated in Figure 1 below.

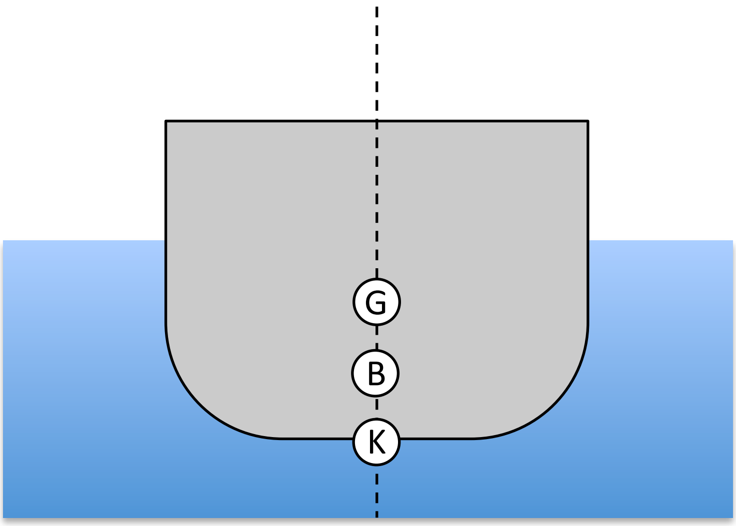


Figure 1 – Hull at Zero Heel Angle

There are three locations labelled with letters. These are really quite simple and are as follows:

- K stands for keel, i.e. the bottom of the keel of the yacht. This is also sometimes called the Baseline by naval architects.
- G stands for gravity. The location of G is the centre of gravity (sometimes called the CofG – centre of gravity). The height of G above the keel is called KG referring to a line between K and G.
- B stands for buoyancy. The location of B describes the centre of buoyancy. The centre of buoyancy can be thought of as the location of the centre of gravity of a body of water with the shape of the underwater part of the hull. Since the hull has pushed all of this water out of it's way, the water pushes back through this centre of buoyancy. So, if you add up all of the forces of the water trying to get back into the space taken up by the

hull, they will be equal to an equivalent force acting though the centre of buoyancy. The height of B above the keel is called KB referring to a line between K and B.

When the hull is upright (or has zero heel angle), the centre of buoyancy is directly underneath the centre of gravity (or centre of mass) of the yacht. This is called static equilibrium.

Things change when the hull is heeled over away from zero heel angle as illustrated in Figure 2.

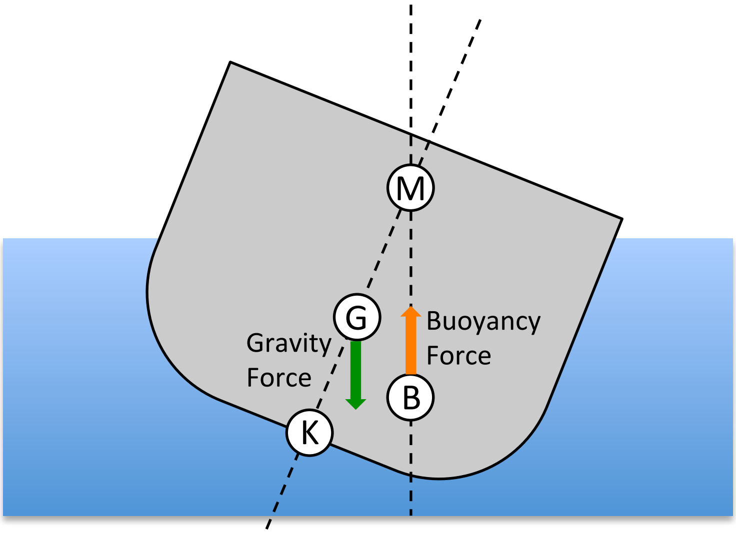


Figure 2 – Hull With Angle of Heel

Note that B has moved to the right.

If the hull was perfectly round like a log, the centre of buoyancy would not move when the log was rolled, resulting in no tendency for the log to roll back upright (which is why a log is so hard to stand on in the water!).

For other shapes, when the hull is heeled over, the shape of the body of seawater pushed out of the way (displaced) by the hull changes, and so does the position of the centre of gravity of this shape (or the centre of buoyancy). You can see that the position of B in relation to the hull shape has moved. For ship-like hulls, the centre of buoyancy moves towards the direction of heel. The result is that the buoyancy force now acts upwards at a distance from the centre of gravity of the hull (which of course does not change regardless of heel angle). The couple produced by the gravity force and the buoyancy force is the 'restoring moment' or the torque acting to roll the yacht back upright into it's equilibrium position.

The really key part of all this is that for small angles of roll (say less than 15 degrees), the location of the point above B that intersects with the yacht centreline (connecting K and G), remains in the same location (approximately). So regardless if the roll angle is 2 degrees or 6 degrees, M remains the same height above K. Since G does not move as the yacht rolls, M also remains the same height above G for all small roll angles. The distance between G and M is called GM. Because we are talking about the transverse axis (athwartships) of the yacht, the subscipt T is added to GM to make it GM_T (or GMt, same thing). So, there you have the GM_T. Since G and M remain in the same location for all small roll angles, GM_T is a fixed length for any given hull shape.

If we now consider Figure 3, another location has been named (Z).

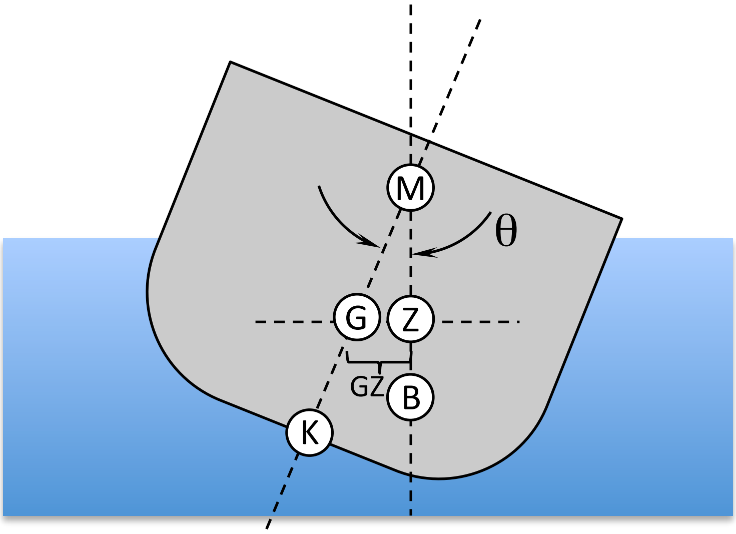


Figure 3 – Distance GZ (Righting Lever)

Z is simply the place where a horizontal line through G intersects with the vertical line going through B and M. Referring back to Figure 2, you can see that the length GZ is the lever arm that the buoyancy force and gravity force are acting about. You can see that as the heeling angle (Θ) increases, B will move further to the right. Therefore the length GZ will increase. In fact GZ varies linealry with roll angle, and using basic trigonometry, it can be seen that;

$$GZ = GMt \times \sin(\Theta)$$

The righting moment (the torque attempting to roll the vessel back upright) is equal to the buoyancy force of the displaced seawater, acting on a lever arm equal to GZ. The higher the roll angle (Θ) the larger GZ is, and therefore the larger the righting moment (RM).

$$RM = Displacement \times g \times GZ$$

$$RM = Displacement \times g \times GMt \times \sin(\Theta)$$

where g = gravitational acceleration, or approx 9.81 $m.s^{-2}$

This is interesting, because GZ varies with roll angle, so cannot be used as a general description of the lever arm for the vessel. However GM_T is a fixed length, and GZ is directly proportional (times roll angle) to GM_T. So GM_T is a very useful length to describe how quickly GZ increases with roll angle, or the relationship between the roll angle and the righting moment. Going back to the analogy between springs and yacht rolling above, this relationship is called the roll 'stiffness'. We can now see that the roll stiffness is directly proportional to the yachts GM_T. Naval architects often speak about GM_T as a direct measure of a yachts stiffness.

What Happens in Real Waves ?

As a wave passes under a yacht, the wave crest approaches the yacht from one side. If the wave length is somewhere near the beam of the yacht, there will be a crest under one side of the yacht and a trough under the other. The yacht on the right has a larger GMt. This means that GZ is larger, and the wave effectively gains more leverage on the yacht with the larger GMt. The result is that in order to counter the wave induced torque with a stabilization system (whether fins, tank or gyro), a larger stabilization system is required.

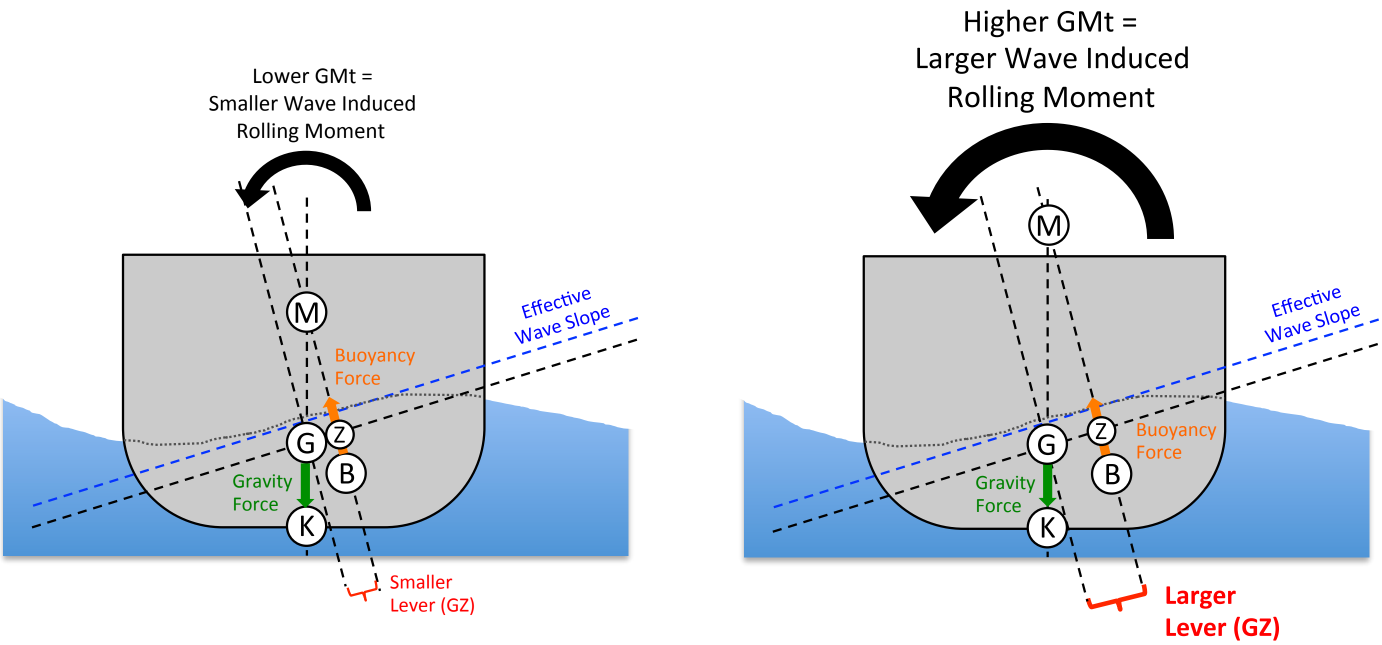


Figure 4 – Induced Wave Torque Lever with Higher GMt

Note that in fact the presentation above is a simplification of what happens. In fact the buoyancy (B) moves even further to the right as the distribution of water below the vessel changes due to wave profile. This makes the effect of high GMt even more pronounced. This effect complicates the presentation and has been omitted for clarity.

So How Does GM_T Influence Yacht Rolling?

A yachts roll stiffness is proportional to the GM_T (for roll angles less than say 15 degrees). A higher GM_T means a more stiff yacht. A lower GM_T means a less stiff yacht. The description 'tender' is used to describe lower stiffness levels. So a more 'tender' yacht is a less 'stiff' yacht. The roll stiffness has two very important impacts on the way a yacht rolls, which will be discussed below.

The Problems with Very Stiff Yachts (high GM_T)

There are two significant problems with excessively high roll stiffness:

1. High stiffness provides a greater lever for a wave passing under the vessel to exert a rolling moment, which leads to more roll for a given wave, and
2. High stiffness reduces the natural rolling period, which leads to faster rolling motion and higher rolling accelerations...which is downright uncomfortable.

Let's discuss each of these outcomes separately.

1. High Stiffness = Greater Lever for Waves to Exert Rolling Moment
= Higher Wave Induced Rolling Moment
= Larger Stabilization System Required !

As discussed above, a higher GM_T increases the roll 'stiffness' of the yacht, which in turn gives waves passing under the vessel a bigger lever to create rolling motion. The result is that any stabilizing system (fin, tank or gyro) must be larger in order to provide greater stabilizing torques to overcome the greater wave induced rolling torques. In fact the size of the stabilizing system goes up pretty much proportionately with GM_T. So if you double the GM_T, you double the torque capacity required of the stabilizing system.

This means that a 30m yacht with displacement of 100 tonnes and GM_T of 2.0m will require a stabilizing system of twice the capacity as the same length and displacement yacht with a GM_T of 1.0m !

2. High Stiffness = Lower Roll Period
= Higher Roll Accelerations
= Reduced Comfort in Waves !!

Every yacht has a natural rolling period (Tn), measured in seconds, that the yacht will prefer to roll at. The rolling period is the time the yacht takes to roll from maximum angle to one side, to max angle on the other side, and then back to max angle on the original side. This changes slightly for different loading conditions, but not usually significantly. It is a characteristic of the yacht.

The significance of the natural rolling period for a yacht is that on average the yacht will roll at this period more often than other periods, even if the period of the waves in which the vessel is operating are not at the yachts natural rolling period.

Now the important point for comfort in waves regarding rolling period is that a smaller rolling period (less seconds to get from one side to the other) causes higher angular accelerations. Angular accelerations contribute significantly to guest discomfort as they strongly influence vertical accelerations, which we all know make people seasick. Angular accelerations also contribute significantly to objects sliding off tables, and glasses toppling over and spilling their contents. None of these outcomes are preferred on a yacht (or any vessel for that matter).

There is sometimes a significant misunderstanding of the term 'stability'. Some shipyards advertise 'highly stable' yacht designs. This almost always refers to high GMt values. Whilst it is true that on a lake, these vessels will roll less when a large mass is moved around the vessel. In waves (during typical operational conditions), the same high GMt leads to shorter natural rolling periods, higher angular accelerations, and ulitimately to a less comfortable yacht. Further, as discussed above, in order to improve the comfort of such a yacht design, a larger than necessary stabilization system is required to overcome the larger wave forces on the yachts hull.

A certain amount of static stability is required in order to prevent the yacht from rolling over on it's side, and also by Classification Society Rules. But beyond these requirements, a more 'tender' design (i.e. lower GMt) will result on a more comfortable yacht that can be made even more comfortable with a smaller stabilization system. This a double win for comfort in waves.

Displacement yachts (with speeds up to around 15 knots) usually have lower GMt as they have rounded bilge hulls and are narrower for propulsive efficiency. Semi-planing and planing yachts often have higher GMt as they feature hard chined, wider and shallow hullforms to allow the yacht to plane. Even for planing yachts, the GMt should be as low as practical given the other contraints on the design.

A low GMt value is in the range between say 0.8m and 1.2m. A moderate GMt value is around the 1.5m mark. GMt values over 2.0m are in the high range. Catamarans can have GMt values above 10m in some cases, which is why stabilizing a catamaran requires massive stabilization torques.

Happily for naval architects, the Tn can be fairly accurately estimated based on some characteristics of the yacht using the formula below, and variations of this. It is also convenient that the inputs to this formula can often also be estimated fairly early in the design stage.

$$T_n = 2\pi \times \sqrt{\frac{I_{44} + I_{added}}{\Delta \times g \times GMt}}$$

where,

I_{44} = Rotational inertia of the the yacht about the roll axis (heavier yacht = higher inertia, mass spread out from keel to superstructure = higher inertia)

I_{added} = Added rotational inertia due to 'attached' water moving with the hull

g = gravitational acceleration ≈ 9.81 m.s^{-2}

Δ = displacement (mass) of yacht in metric tonnes

The important point here is that the GMt is on the bottom of the equation. This means that a large GMt equals a low rolling period.

Conclusions and Recommendations

There are sevaral take aways from the discussion above that will help you think about yacht rolling motion and the stabilization of this.

- High static stability (high GMt) does not lead to more comfort in waves...exactly the opposite.
- The GMt should only be as high as is required. Higher values of GMt can lead to reduced comfort in waves.
- GMt is higher for yachts that have higher beam (width across the hull), and more pronounced chines.
- High GMt leads to high roll 'stiffness', which leads to higher angular accelerations and larger required stabilization systems.
- The oppposite of a 'stiff' yacht is a 'tender' yacht. Tender yachts are generally more comfortable in waves.
- Excessively 'tender' yachts can suffer from larger roll angles, but this is usually more comfortable than the high accelerations associated with stiff yachts.
- GMT, GM_T, GMt, GM_t and GM(t) are all the same thing. Of course GMT is also Greenwich Mean Time, which is why the other forms are more commonly used.
- The GMt (along with maximum waterline beam and displacement) is a key input to VEEM's GyroSize online gyro stabilizer sytem sizing tool.
- The GMt can be found in the Stability Booklet. This Booklet is required to be stored on the bridge of the yacht.

…What next?

The following sections describe two powerful tools that can assist you to understand what configuration of VEEM Gyro(s) is appropriate for your yacht. The effect of GMt is all covered within these analyses.

GyroSize superyacht

Online gyro sizing calculator

GyroSize is a free online calculator that provides a detailed PDF report describing the VEEM Gyro installation options suitable for your yacht based on simple vessel characteristics.

The vessel data required to run a GyroSize calculation is:

- BWL (maximum waterline beam)
- Vessel Displacement (Full or Half Load Intact Condition)
- GMt (transverse metacentric height)

All of this data is available in the yachts Stability Booklet, located on the bridge.

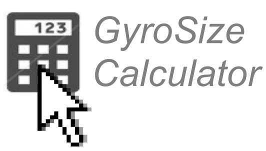
Gyro stabilizer installations suited to the following Operational Profile options will be presetnted for your review and selection:

Operational Profile	Sea State	Waves up to
Profile 1 – Sheltered Water	2	0.5 m
Profile 2 – Coastal Water	3	1.25 m
Profile 3 - Open Water	4	2.5 m
Profile 4 - Blue Water / Ocean Explorer	5	Rough

Choosing the Operational Profile that most accurately reflects your intented yacht usage will ensure that the gyro installation selected will provide you with a level of stabilization that matches your expectations. If you are unsure, please speak to VEEM or your local VEEM agent to discuss the most suitable profile for you.

Access tool at www.veemgyro.com/gyro-size/

Or by simply clicking on this button on our website:



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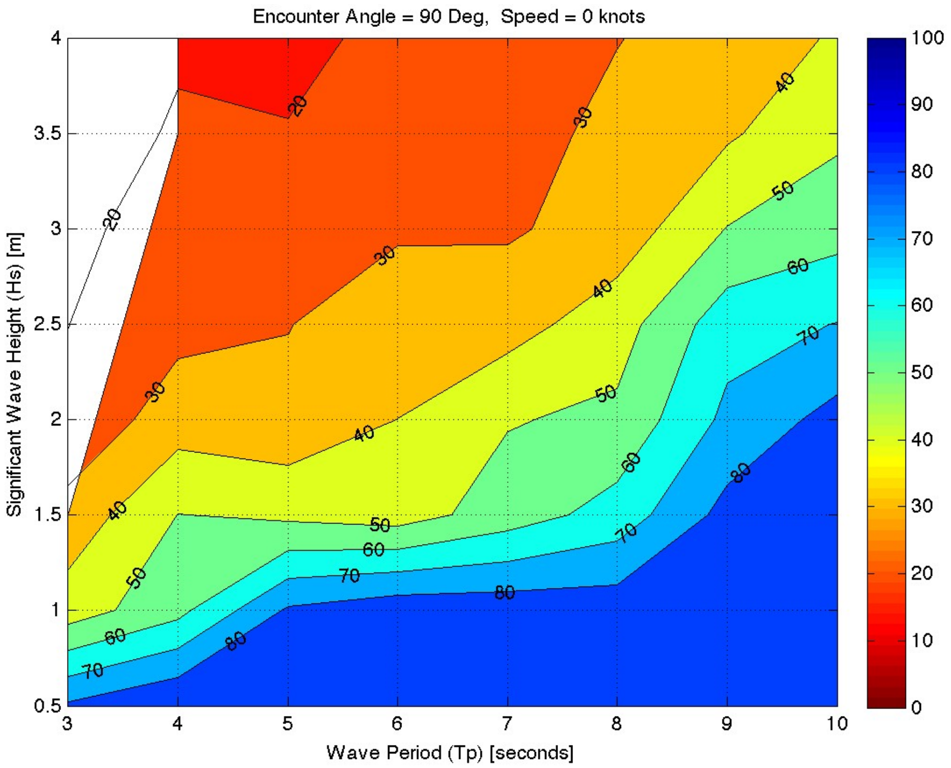
GyroSIM – VEEM's Detailed Time Domain Simulation

Once you have accessed the GyroSize online calculator and decided what gyro stabilizer configuration(s) best suit your yacht, speak to VEEM about a detailed numerical analysis using our GyroSIM software. This analysis will tell you exactly how much roll reduction you can expect for a wide range of possible wave conditions.

VEEM's *GyroSIM* software is a detailed time domain simulation that takes as input a realistic irregular (random) seaway based on known mathematical representations. It considers the actual active precession controller used on the gyro units, and accurately simulates the motion of the vessel in random realistic waves with the gyro switched off and with the gyro switched on. The result of a large number of rigorous time domain simulations is presented in a very informative color contour plot that gives the % roll angle reduction at a large number of wave height and wave period combinations.

A sample graphical performance chart is presented below.



This chart displays % roll reduction as the contours (see legend in % to right). The percentage roll reduction (%RR) is the percentage reduction in RMS roll angle that is expected when the Gyro is turned ON. To use the chart, simply select a wave height and wave period combination and read off the predicted %roll reduction from the contour.

Request a simulation report at www.veemgyro.com/enquiries/