# The Stability Assessment of Small Working Craft Without Reference to Hydrostatic Data

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*ABSTRACT*

*The initial stability of a vessel can be evaluated by the established procedure of the inclining experiment, provided that the vessel's lines or hydrostatics are available. For many small working craft however no record exists of these particulars, and therefore the inclining experiment can only be undertaken if it is accepted that the lines will also have to be taken from the vessel in order to generate the necessary data. This paper explores the relationship between the roll period and the metacentric height and demonstrates that in theory it is possible to evaluate the initial stability from the change in roll period as a pair of weights are moved vertically and horizontally above the deck, without requiring reference to any hydrostatic data. A procedure requiring only five observations is described, and the necessary calculations detailed, however the difficulties in implementing such a procedure are also discussed. Further work to identify extensions to this procedure which could be of practical use to a surveyor are outlined.*

## INTRODUCTION

The conventional procedure for evaluating a vessel's initial stability is the inclining experiment, in which weights are moved across the deck and the angle of heel measured. By reference to the hydrostatic particulars of the vessel in the trial condition the metacentric height and position of the centre of gravity can be found. However for many small craft, such as fishing and other work boats, neither the hull lines nor the hydrostatic data are available. The results of an inclining experiment can only be interpreted, therefore, if the lines are also taken off the vessel and the necessary data derived. Clearly this adds considerably to the cost and practicality of the inclining experiment as a way of assessing the initial stability for such craft.

Methods for obtaining an estimate of initial stability for such vessels, based on the natural period of roll, have long been recognised. These rely on the use of a stop watch to measure the roll period, and assumptions concerning the transverse mass moment of inertia of the vessel. In the first part of this paper it will demonstrated however, that in theory it is possible to derive the vessel's initial stability (together with the vertical centre of gravity and displacement) by a direct calculation which uses as its only input the periods of roll as a pair of weights are positioned in pre-defined

**Table 1: Nomenclature**

| | |
|---|---|
| $B$ | breadth of vessel |
| $d$ | vertical distance weights moved |
| $\Delta$ | displacement of vessel |
| $f$ | a correlation factor |
| $g$ | acceleration due to gravity |
| $\overline{GM}$ | metacentric height (initial stability) |
| $h$ | $x$ offset of ellipse centre |
| $I'$ | effective mass moment of inertia |
| $k$ | $y$ offset of ellipse centre |
| $m$ | combined mass of weights |
| $T$ | vessel's natural period of roll |
| $u$ | minor demi-axis of ellipse |
| $v$ | major demi-axis of ellipse |
| $x$ | horizontal co-ordinate |
| $y$ | vertical co-ordinate |

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locations on and above the deck. The success of such a procedure depends on the ability to measure the period of roll to a high degree of accuracy, and while modern computer technology provides more than adequate precision, interference from hydrodynamic factors associated with the vessel reduce the accuracy achievable. These difficulties are described in the latter part of this paper, which culminates with a discussion of how such a procedure may be practically implemented to provide stability data for a small craft without reference to its lines or hydrostatics.

## THE RELATIONSHIP BETWEEN INITIAL STABILITY AND THE PERIOD OF ROLL

The link between stability and a vessel's natural period of roll has been acknowledged for several centuries, indeed it was reported that in 1628 a roll experiment aboard the *Vasa* was halted due to the alarming results [1]. Unfortunately this did not prevent the vessel's loss due to capsize on her maiden voyage.

The period of roll is still used today to assess the stability of fishing vessels. For example the Marine Safety Agency suggests that by obtaining an average time for the period of roll (*T*) by stop watch, the metacentric height of a vessel ( $\overline{GM}$ ) can be estimated from the following formula [2]:

$$T = \frac{fB}{\sqrt{\overline{GM}}} \qquad (1)$$

This expression uses the breadth of the vessel (*B*), and a correlation factor (*f*). The value of the correlation factor is dependent on the vessel type. In metric units it varies form 0.95 for double boomed beam trawlers, to 0.60 for vessel's with a live fish well. If an appropriate value of the correlation factor can be identified, then the initial stability $\overline{GM}$ can be estimated from the results of a basic roll test. While this may be satisfactory in many cases, it can be envisaged that on occasion there could be considerable error, especially where the vessel does not conform to a recognised class of craft, or where it has been substantially modified.

It is possible however to define the precise relationship between stability and the period of roll which can be defined by considering the righting moment at small angles of heel, and assuming simple harmonic motion. It can then be shown [3] that the period of roll, *T*, is given by:

$$T = \frac{2\pi\sqrt{I'}}{\sqrt{g\Delta\overline{GM}}} \qquad (2)$$

In this expression there are three vessel related variables: the displacement ( $\Delta$ ), the effective transverse mass moment of inertia which includes the effects of added mass ( $I'$ ), and the metacentric height ( $\overline{GM}$ ). The last of these is considered the measure of initial stability, and it is the relationship of this with the period of roll, *T*, which is of interest. However it is the presence of the other two variables which complicates the direct assessment of stability from the period of roll. (It is worth noting that equations 1 and 2 are of the same form if it is accepted that the radius of gyration is a function of the vessel's beam).

## GEOMETRY AND THE PERIOD OF ROLL

In the inclining experiment weights are moved across a vessel's deck and the induced angle of heel noted. The movement of weights also impacts on the period of roll, but as an angle of heel is not desired for a roll based experiment pairs of weights must be moved symmetrically about the centre plane of the vessel. The period of roll will be affected by moving such pairs of weights horizontally away or toward the centre plane, or by moving them vertically, as both actions affect either the position of the vertical centre of gravity (and hence $\overline{GM}$ ), or the mass moment of inertia, or both. By considering how changes in the geometric position of a pair of such weights influences the period of roll, it is possible to devise a procedure in which both the metacentric height and the mass moment of inertia can be changed in a systematic way. In theory the observed changes in the period of roll can then be used with equation 2 to find the initial stability of the vessel, without recourse to correlation factors.

Moving the weights only horizontally has no impact on the vertical centre of gravity (and therefore does not alter $\overline{GM}$ ), but it does alter the mass moment of inertia. By using Pythagoras's theorem it can be shown that regardless of where the vertical centre of gravity is located this change in the mass moment of inertia ( $I'$ ) is given by equation 3, where the mass of the combined weights are *m*, and the dimensions $x_a$ and $x_b$ are as defined in Figure 1. Moving the weights away from the centre plane increases the mass moment of inertia, and vice versa.

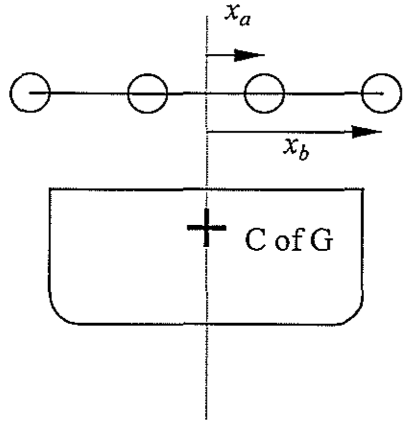


**Figure 1:** Horizontal definition for two positions of a pair of weights placed symmetrically about the centre plane.

$$\delta I' = m\left(x_b^2 - x_a^2\right) \qquad (3)$$

Vertical movement of the weights clearly changes the vertical centre of gravity, and hence the metacentric height. This effect is given by equation 4, where *d* is the vertical distance that the weights are moved:

$$\delta \overline{GM} = \frac{md}{\Delta} \qquad (4)$$

A purely vertical movement of the weights also alters the mass moment of inertia, but it is impossible to establish the magnitude of this change without knowing the position of the vertical centre of gravity. It is evident however that a downward movement of the weights will reduce the mass moment of inertia, provided that the weights remain above the vessel's centre of gravity. As a movement of the weights outboard increases the mass moment of inertia it is possible to both lower the weights and simultaneously move them horizontally such that the net change in the mass moment of inertia is zero. For this to be the case as the weights are lowered they must follow an elliptical path, which starts on the centre plane, and is furthest form the centre plane when the weights are at the same height as the vessel's own centre of gravity, as shown in Figure 2.

The fact that the locus of the weight positions for constant $I'$ follows an elliptical path can be used to derive another equation. If the centre of gravity did not change as the weights were moved, then the locus for constant $I'$ would describe a circle. The distortion of the circle into an ellipse is due to the downward drift of the centre of gravity as the weights are lowered. The difference between the major and minor demi-axes of the ellipse, *v* and *u*, is a measure of the change in the vertical position of the centre of gravity:

$$\delta \overline{GM} = v - u \qquad (5)$$

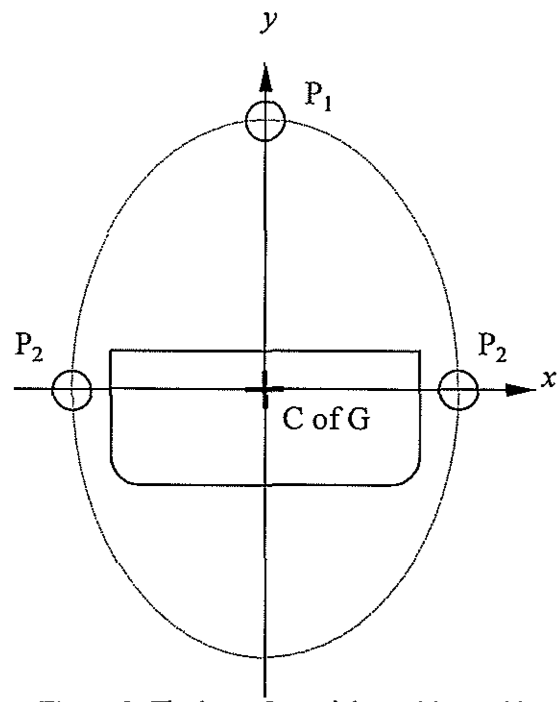


**Figure 2:** The locus for weight positions with a constant mass moment of inertia.

**THE BASIS OF DIRECT ASSESSMENT OF STABILITY**

It is the existence of this locus for weight positions which will maintain a constant mass moment of inertia which enables a direct evaluation of initial stability. If the period of roll is measured when the weights are on the centre line and high above the deck, and then the position is identified which corresponds to the maximum outboard location of weights with the same mass moment of inertia, and the roll period is again measured, sufficient data will have been gathered to calculate the metacentric height.

The theory can be easily summarised as follows. For the two cases observed (with the weights in positions 1 and 2 as shown in Figure 2) both the vessel's displacement ($\Delta$) and mass moment of inertia ($I'$) are unknown, although they have the same value in each case. The metacentric height ($\overline{GM}$) however, is different in each case. There are therefore four unknowns: $\Delta$, $I'$, $\overline{GM}_1$ and $\overline{GM}_2$. To solve this problem four equations are needed. The basic equation for the period of roll, equation 2, can be used twice with the appropriate values $T_1$ and $T_2$ being used with $\overline{GM}_1$ and $\overline{GM}_2$ respectively. In addition the difference between $\overline{GM}_1$ and $\overline{GM}_2$ is defined in two independent ways in equations 4 and 5. These can be used to provide the third and fourth equations which can be re-stated as in equations 6 and 7 below:

$$\overline{GM_2} - \overline{GM_1} = \frac{m(y_1 - y_2)}{\Delta} \qquad (6)$$

$$\overline{GM_2} - \overline{GM_1} = y_1 - y_2 - x_2 \qquad (7)$$

With four equations for four unknowns the problem is solvable, however this theory presupposes that the ellipse describing weight positions with a constant value of $I'$ can be found. To demonstrate how this can be achieved it is necessary to consider again how the geometry of the weight positions effects the relevant variables. As already discussed the weights can be moved horizontally only, so keeping $\overline{GM}$ constant, or they can be moved along an elliptical path which maintains $I'$ constant. There is however a third path which will alter both $\overline{GM}$ and $I'$ in such a way that the period of roll, $T$, is kept constant, as shown in Figure 3.

This third locus, where $T$ is constant, has a property which can be used to find the locus for constant $I'$.

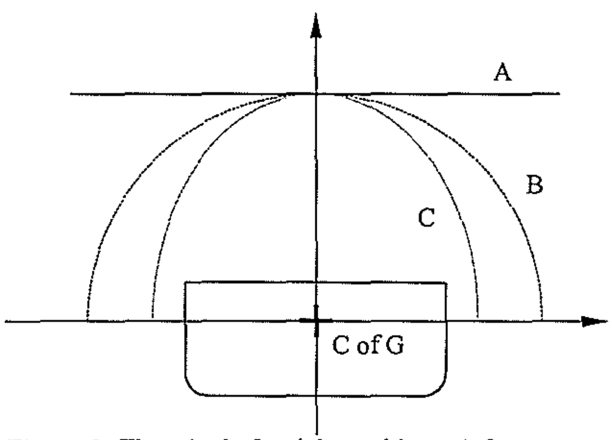


**Figure 3:** Three loci of weight positions: A for constant metacentric height; B for constant period of roll; C for constant mass moment of inertia.

This can be shown by first manipulating equation 2 to obtain a general expression for the partial derivative of $I'$ with respect to $\overline{GM}$:

$$\frac{\partial I'}{\partial \overline{GM}} = \frac{T^2 g \Delta}{4\pi^2} \qquad (8)$$

Evidently when the weights are moved along the locus that maintains the period of roll, $T$, constant, then this partial derivative is also a constant. If weights positioned on the centre plane are taken as a first case, and a second position is found below this, where the weights are positioned outboard such that the two periods of roll are the same, then the change in $I'$ from the first case to the second can be found from the product of the partial differential of $I'$ with respect to $\overline{GM}$ and the actual change in $\overline{GM}$:

$$\delta I' = \frac{\partial I'}{\partial \overline{GM}} \delta \overline{GM} \qquad (9)$$

which, by substituting from equations 8 and 4, yields:

$$\delta I' = \frac{T^2 gmd}{4\pi^2} \qquad (10)$$

From this expression the change in the mass moment of inertia between the first position (high on the centre plane) and the second position (with weights lower and outboard as shown in Figure 4) can be calculated. As it is possible to calculate the change in the mass moment

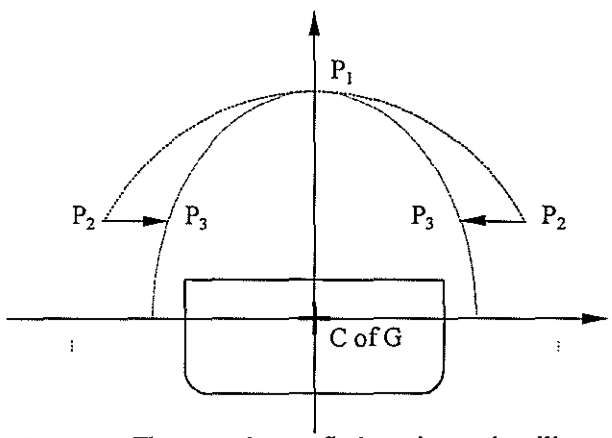


**Figure 4:** The procedure to find a point on the ellipse with constant mass moment of inertia: by experiment $P_2$ is found where the period of roll is as for $P_1$, then $P_3$ is calculated such that $\delta I$ from $P_2$ to $P_3$ is the same as $\delta I$ from $P_1$ to $P_2$.

of inertia when the weights are moved purely horizontally, from equation 3, so the distance toward the centre plane that the weights should be transferred in order to restore the mass moment of inertia to the same value as for the first position can be calculated.

Identifying points on the ellipse which defines the locus of constant mass moment of inertia can therefore be achieved. Having shown that this is possible it follows that the direct evaluation of initial stability on the basis outlined above is theoretically valid.

## A CALCULATION REQUIRING THE MINIMUM NUMBER OF OBSERVATIONS

The direct evaluation of initial stability is based on the identification of two positions which are on the major and minor axes of an ellipse which is centred on the centre of gravity of the vessel. The period of roll when the weights are located at these positions must be established in order to provide the four equations necessary to proceed with the theoretical calculation. In this section a calculation will be described which uses five observations, the theoretical minimum number, however in the next section the practical difficulties of implementing this simplest of procedures will be discussed.

In this procedure the pair of weights are first positioned together on the centre plane well above the deck. This position is taken to be the extreme vertical point of an ellipse around which the weights can be moved without altering the mass moment of inertia. By positioning the weights in four more locations, and recording the period of roll, it is theoretically possible to find all the desired results, including the initial stability, by using the nine stage calculation summarised below.

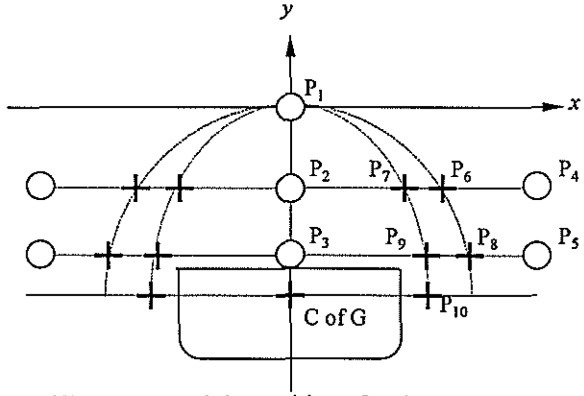


**Figure 5:** Weight positions for the procedure to calculate initial stability: Positions $P_1$ to $P_5$ are observed experimentally, positions $P_6$ to $P_{10}$ are derived and the period of roll calculated.

The five weight positions necessary are as follows: the first is with both weights together on the centre plane, as high as is practicable above the deck, the second at about half the height of the first (again on the centre plane), and the third on or near the deck (also on the centre plane). The fourth and fifth positions have the weights located at the same heights as the second and third respectively, but at some distance from the centre plane. These positions are shown in Figure 5, as are all the additional positions described below for which data is derived. The calculation uses the first position to define the ellipse of interest, as it is taken to be the extreme point of the ellipse's major axis. This point is also taken as the origin in defining the $x$ and $y$ co-ordinates of the other positions. The calculation to find the extreme point of the minor axis then proceeds in stages 1 to 5 below. The vertical position of this point is the same as the vessel's centre of gravity. Stages 6 to 9 below demonstrate how the mass moment of inertia, the displacement and the metacentric height are also derived.

1. Positions 2 and 4 are used to find position 6 (which is at the same height as position 2). This will have the same period of roll as position 1. This is achieved by reducing equation 2 to a simple form which defines the relationship between the period of roll and the distance of the weights from the centre line, given that the weights can only be moved horizontally, and therefore that $\overline{GM}$ will not change.

If the constants $c_1$, $c_2$ and $c_3$ represent $\left(2\pi/\sqrt{g\Delta\overline{GM}}\right)$, $\left(I' + my^2\right)$ and $(m)$ respectively, then equation 2 can be written as:

$$T = c_1\sqrt{c_2 + c_3x^2} \qquad (11)$$

By further combining the constants this relationship reduces to an expression with only two unknown constants, $a$, and $b$:

$$T = ax^2 + b \qquad (12)$$

By substituting for $T_2, x_2$ and $T_4, x_4$ it is possible to find $a$ and $b$.

Setting $T_6 = T_1$ it is possible to find $x_6$ from the same equation.

2. Position 7 (also at the same height as 2) which will have the same mass moment of inertia as position 1 is then found from equations 10 and 3 as discussed above, and the period of roll at this position again interpolated form the observed periods for positions 2 and 4.

From equation 10:

$$\delta I'_{(1\text{ to }6)} = \frac{T_1^2 gm(y_1 - y_6)}{4\pi^2} \qquad (13)$$

(an increase in $I'$)

And from equation 3:

$$\delta I'_{(6\text{ to }7)} = -m\left(x_6^2 - x_7^2\right) \qquad (14)$$

(a decrease in $I'$)

As $\delta I'_{(1\text{ to }6)} = -\delta I'_{(6\text{ to }7)}$ it is possible to find $x_7$. Interpolate to find $T_7$.

3. Positions 3 and 5 are used in a similar way to establish the position and period of roll for positions 8 and 9. Position 9 has the same mass moment of inertia as positions 1 and 7.

4. Positions 1, 7 and 9 are three points on the required ellipse and can be used in the standard equation for such a curve to calculate the major and minor demi-axes, $v$ and $u$.

The standard equation for an ellipse, centred at $(h,k)$, and with the minor and major demi-axes defined as $u$ and $v$, is given by:

$$\frac{(x-h)^2}{u^2} + \frac{(y-k)^2}{v^2} = 1 \qquad (15)$$

If position 1 is defined as (0,0) and is on the major axes with the ellipse below it, it can be shown that $h = 0$ and $k = -v$.

In this case the equation for the ellipse simplifies to:

$$\frac{x^2}{u^2} + \frac{(y+v)^2}{v^2} = 1 \qquad (16)$$

Use $(x_7, y_7)$ and $(x_9, y_9)$ to find $u$ and $v$.

5. The dimensions of the demi-axes fully define the ellipse. They therefore give the position of the vessel's centre of gravity in relation to position 1, and the extreme horizontal position possible for the weights such that the mass moment of inertia is the same as in position 1, i.e. position 10.

The vessel's centre of gravity is given by: $(0,-v)$.

Position 10 is given by $(u,-v)$.

6. The mass moment of inertia for all points on the ellipse is found from any two points on the ellipse at which the period of roll is known, such as positions 1 and 9. This is achieved by using equation 2 for both positions, and then subtracting one from the other to obtain an expression for the change in metacentric height. Equation 4 provides an alternative expression for this, and if the two are equated it is found that displacement (the other unknown variable) is cancelled from the equation, and so the mass moment of inertia can be found.

From equation 2:

$$\delta \overline{GM}_{(1\text{ to }9)} = \frac{4\pi^2 I'}{g\Delta T_9^2} - \frac{4\pi^2 I'}{g\Delta T_1^2} \qquad (17)$$

From equation 4:

$$\delta \overline{GM}_{(1\text{ to }9)} = \frac{m(y_9 - y_1)}{\Delta} \qquad (18)$$

From which $I'$ can be found:

$$I' = \frac{mg(y_9 - y_1)}{4\pi^2}\left(\frac{T_9^2 T_1^2}{T_1^2 - T_9^2}\right) \qquad (19)$$

7. The change in the metacentric height between positions 1 and 10 can be expressed in terms of moments, equation 4, or in terms of the geometry of the ellipse, equation 5. As position 10 is now defined, as are the demi-axes of the ellipse, equations 4 and 5 can be used to find the displacement of the vessel.

From equation 4:

$$\delta \overline{GM}_{(10\text{ to }1)} = \frac{m(y_{10} - y_1)}{\Delta} \qquad (20)$$

From equation 5:

$$\delta \overline{GM}_{(10\text{ to }1)} = v - u \qquad (21)$$

From which $\Delta$ can be found:

$$\Delta = \frac{m(y_{10} - y_1)}{v - u} \qquad (22)$$

8. In stages 6 and 7 above the mass moment of inertia and the displacement have been found. Therefore

equation 2 can be used to find the metacentric height for any point on the ellipse for which the roll period is known, such as position 1.

From equation 2:

$$\overline{GM}_1 = \frac{4\pi^2 I'}{g\Delta T_1^2} \qquad (23)$$

9. The metacentric height at position 1 can be corrected to that of position 10, when the weights are at the same vertical height as the vessel's own centre of gravity, by adding the difference between $v$ an $u$ to $\overline{GM}_1$. This then gives the initial stability of the vessel, which is the principal objective of the calculation.

$$\overline{GM} = \overline{GM}_1 + (v - u) \qquad (24)$$

## THE DIFFICULTIES OF IMPLEMENTATION

The calculation described above is clearly considerably more complex than that associated with the conventional inclining experiment. It can however be easily implemented as an algorithm for a spread sheet which takes as its input the size of the weights, their five relative positions, and the associated five periods of roll. The primary output is the metacentric height, $\overline{GM}$, but vessel's vertical centre of gravity, displacement, and effective mass moment of inertia are also results of the calculation.

An implementation of such a spread sheet has demonstrated that the calculation is valid when tested against the output of a mathematical model of the roll period of a vessel. This is only to be expected as both the model and the calculation are based on the equaition describing the period of roll (Equation 2). However attempts to use this procedure to evaluate the initial stability of a model barge in a test tank produced results which were quite unacceptable, with errors on occasion in excess of 100%.

The explanation for this can be found if consideration is given to the precision required in measuring the period of roll. By deliberately introducing an error into the spread sheet calculations the impact of inaccuracies in the period of roll can be assessed. Such calculations for a hypothetical vessel with a displacement of 5 tonnes, an initial metacentric height of 1 metre, and an effective mass moment of inertia of 10 tonne metres$^2$ were carried out, using weights with a combined mass moment in the order of 2.5 tonne metres. The resulting error in the calculation of the metacentric height depended on the sequencing of the individual errors for each weight position, in terms of a negative or positive error from the true period of roll. If each weight position is assumed to have either the maximum or minimum error, then there are $2^5$ arrangements of errors for the five weight positions, and although many of these prove to have little impact on the final result the worst cases have a severe impact, as shown in Table 2 below.

**Table 2: Example of Maximum Errors**

| Precision of observation (seconds) | Maximum error in $\overline{GM}$ (metres) |
|---|---|
| $10^{-3}$ | 0.055 |
| $10^{-2}$ | 0.59 |
| $10^{-1}$ | 490 |

As can be seen the precision required is in the order of one thousandth of a second for acceptable results to be obtained, and if a precision of only one tenth of a second is the best that is possible then the results can be ridiculous.

Unfortunately the difficulty in obtaining the period of roll with such precision is not one of measurement. An electronic inclinometer linked to a portable PC was used in the model tests mentioned above, and has also been used to measure the period of roll of a variety of small craft in a marina. The equipment was capable of recording the period of roll to an accuracy of $5 \times 10^{-4}$ seconds, which is clearly adequate. The difficulty arises because of the vessels, when observed to this degree of accuracy, fail to perform in a consistent manner. Regrettably a rolling vessel is far from being a perfect signal generator. In the controlled conditions of the test tank results in the order of $10^{-2}$ seconds is possible, however in the marina trials even a precision of $10^{-1}$ seconds could not be counted upon. These results when compared with the table above are in keeping with the tank test results being in error by as much as 100%. They also suggest that implementation of the minimum observation procedure is not viable in practice.

Despite the unpromising outcome of the experimental trials, they do suggest alternative procedures that may prove workable. The errors indicated in Table 2 are the maximum possible error, given the specified level of precision in recording the period of roll. In reality the probability of obtaining such an error is quite small. Clearly if the number of observations were increased the likelihood of an error of these magnitudes affecting the final result would be decreased. The increased number of observations need not be used just to obtain a better average value for each of the five weight positions, but could include observations of additional weight positions. This would necessitate a change in the calculation, but could be used to find both Equation 12 and Equation 16 by a least squares method. Such a procedure would be amenable to a statistical analysis to identify a confidence interval associated with the resulting calculation of the metacentric height. These ideas have not yet been fully explored but are the subject of ongoing research.

Before concluding it should be noted that even if these theoretical difficulties can be resolved the practical application of this procedure would require the introduction of relatively large moments when the pair of weights are shifted. The induced changes in the period of roll are dependant on the magnitude of the change in moment due to the mass of the weights and the distances they are moved. In their highest position the weights must not cause negative stability, therefore the maximum possible vertical moment is $\Delta\overline{GM}$. For practical reasons however, it is desirable to keep the moment to a minimum in order to avoid having to support large masses at positions remote from the deck and centre line. The two outboard positions are used to find the positions where $T$ is the same as when the weights are high up on the centre plane. For this to be achieved by interpolation the experimental position must be further outboard than the required position for constant $T$. If this is not the case the required position will have to be extrapolated, so exaggerating any errors introduced to the data. If this requires the weights to be placed outboard of the vessel's bulwark, consideration will have to be given as to how the weights can be supported in the correct location. As it is clear that the weights will have to be a substantial proportion of the vessel's displacement, probably between one and ten percent, both their handling and accurate positioning dictate that this procedure can only be considered viable for small craft.

## Conclusion

In this paper a procedure has been described whereby the metacentric height, vertical centre of gravity, and displacement of a vessel can theoretically be established without reference to the vessel's geometry, i.e. its lines or hydrostatic data. This is achieved be a direct calculation which uses as its only input the periods of roll, measured with computer assisted precision, as a pair of weights are moved to predefined locations on and above the deck. The basis of this procedure is that as the metacentric height and mass moment of inertia are changed in a systematic way, all the unknown variables in the basic equation for the period of roll can be evaluated.

The assessment of initial stability by this method is only necessary where the hydrostatic particulars of a vessels are not available, as if this information is to hand a conventional inclining experiment could be undertaken. However the large number of older fishing and other work boats around the world for which no record of lines or hydrostatics exists suggests that such a procedure could be considered, especially as national and international bodies increasingly include smaller vessels in their regulatory requirements. It will be necessary to assess the stability of these work boats in a manner which is both practically and economically viable, otherwise the owners will try to avoid regulation by working without certification, and therefore both illegally and unsafely.

The theory behind this procedure, demonstrated conceptually, has a certain elegance which may be pleasing to the naval architect. The surveyor however will question the practicality of locating substantial weights both above the deck, and away from the centre line, possibly even outboard of the vessel's bulwark. For this reason a detailed calculation has been suggested which minimises the number of locations for which observations of the period of roll are required. However experimental observations have indicated that the precision obtainable for the period of roll in the surveyors working environment would be liable to cause an unacceptable level of error. An extension of the procedure has been outlined that would enable the level of confidence in the result of the stability assessment to also be calculated. If future work can demonstrate that such a procedure is viable it should still be noted that this method can only be considered for small craft as the weights required must be in the order of five percent of the vessel's displacement. It is however the smallest of working craft for which records of hydrostatics are least likely to exist. These therefore are the very vessels for which an inclining experiment is not immediately possible, nor the cost of taking off the lines acceptable. Further work is being undertaken to develop the theoretical procedure described in this paper such that it is both economically acceptable and practically viable.

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