Experiment Instructions

HM150.06 Stability of a Floating Body

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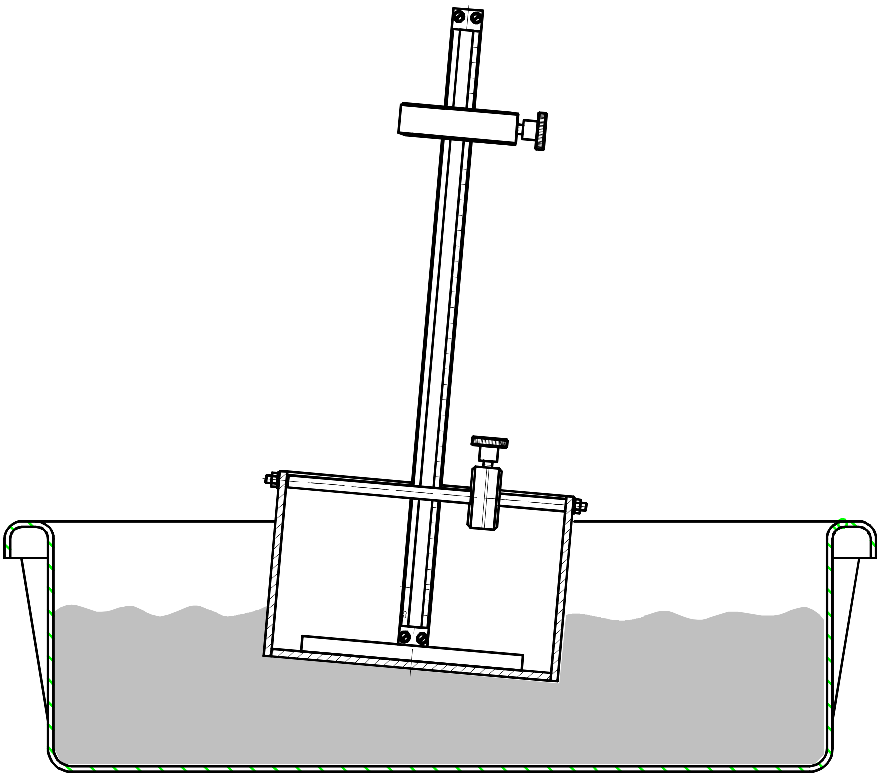

Experiment Instructions

Please read and follow the safety instructions before the first installation

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1 Introduction

The position of the so-called metacentre, the metacentric height, is of crucial significance to the stability of a floating body.

The metacentric height is an essential factor when assessing the stability of a ship in waves.

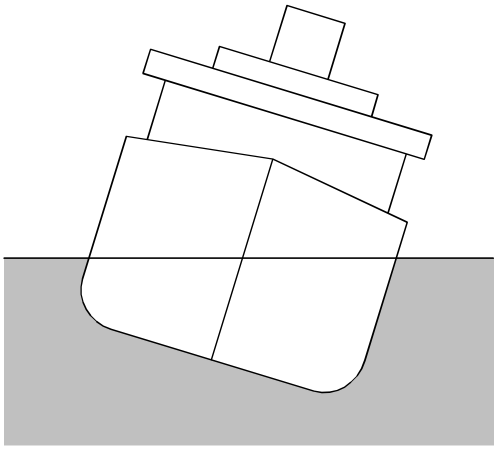


Fig. 1.1 Heeling of a ship

The **Stability of a Floating Body HM 150.06** permits concepts such as

- Buoyancy
- Centre of gravity
- Centre of buoyancy
- Metacentre
- Heel

to be experimentally investigated.

The apparatus is of simple, clear design and is particularly suitable for practical work in small groups.

2 Unit Description

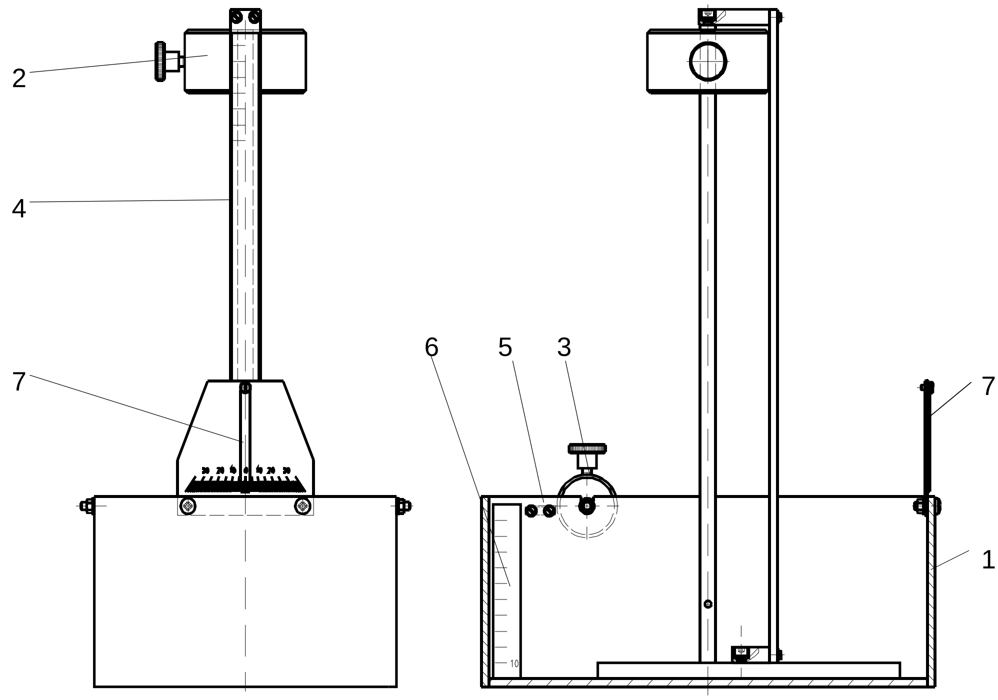


Fig. 2.1 Side and front view

The unit essentially consists of a pontoon (1) and a water tank as float vessel.

The rectangular pontoon is fitted with a vertical sliding weight (2) to permit adjustment of the height of the centre of gravity and a horizontal sliding weight (3) to generate a defined heeling moment. The sliding weights can be fixed in position using knurled screws.

The positions (4, 5) of the sliding weights and the draught (6) of the pontoon can be read off scales. A heel indicator (7) with scale in degrees is also provided.

3 Theory

3.1 Buoyancy

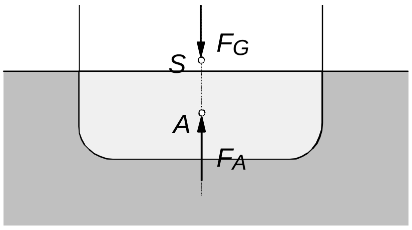


Fig. 3.1 Buoyancy

A body floats in a liquid if the buoyancy of the fully immersed body is greater than its weight. It will only sink into the liquid until the buoyancy F_A corresponds exactly to its dead weight F_G. The buoyancy is then the weight of the water displaced by the body. The centre of gravity of the displaced water mass is referred to as the centre of buoyancy *A*. The centre of gravity of the body is known as the centre of mass *S*.

3.2 Stability of Floating Body

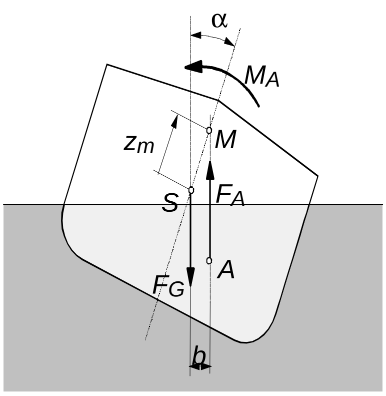
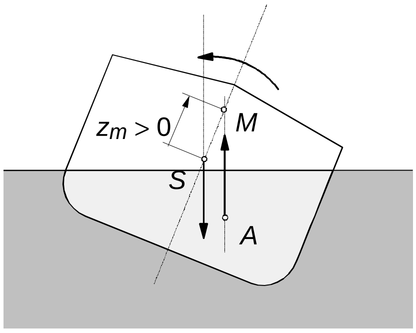


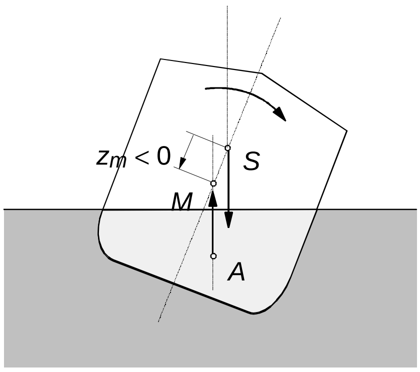
Fig. 3.2 Metacentre and metacentric height

For a floating body to be stable, buoyancy F_A and dead weight F_G must have the same line of action and be equal and opposite (Fig.:3.1). Stability does not necessarily demand that the centre of mass *S* be below the centre of buoyancy *A*.

Of far greater importance is the existence of a stabilising, resetting moment in the event of deflection or heel α out of the equilibrium position (Fig.:3.2). Dead weight F_G and buoyancy F_A then form a force couple with distance b, which provides a righting moment. This distance or the distance between the centre of gravity and the point of intersection of line of action of buoyancy and gravity axis, is a measure of stability. This point of intersection is referred to as the metacentre *M* and the distance between the centre of gravity and the metacentre is called the metacentric height z_m.



stable



unstable

Fig. 3.3 Metacentre and stability

The following conditions then apply to stable floating:

- **Stable floating of a body** occurs when the metacentric height z_m is positive, i.e. the metacentre *M* is above the centre of gravity *S* (Fig. 3.3, top).

$$z_m > 0$$

- **Unstable floating of a body** occurs when the metacentric height z_m is negative, i.e. the metacentre *M* is below the centre of gravity *S* (Fig.3.3, bottom).

$$z_m < 0$$

3.3 Determination of Metacentre Position

The position of the metacentre is not governed by the position of the centre of gravity. It merely depends on the shape of the portion of the body under water and the displacement. There are two methods of determining the position by way of experiment.

In the first method, the centre of gravity is laterally shifted by a certain constant distance x_S using an additional weight, thus causing heeling to occur. Further vertical shifting of the centre of gravity alters the heel α . A stability gradient formed from

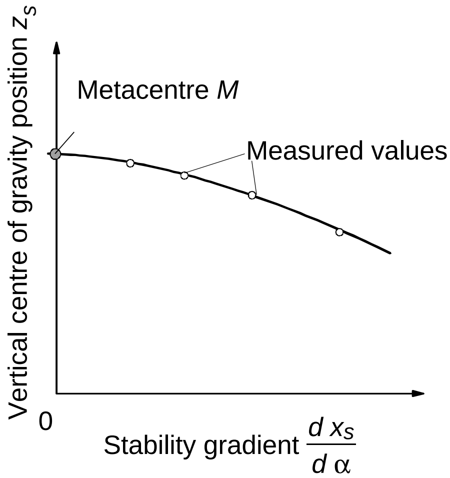


Fig. 3.4 Graphical determination of metacentre

the derivation $\frac{d\,x_S}{d\,\alpha}$ is then defined. The stability gradient decreases as the vertical centre of gravity position approaches the metacentre. If centre of gravity position and metacentre coincide, the stability gradient is equal to zero and the system is metastable.

This problem is most easily solved using a graph (Fig. 3.4). The vertical centre of gravity position is plotted versus the stability gradient. A curve is drawn through the measurement points and extended as far as the vertical axis $\frac{d\,x_S}{d\,\alpha} = 0$. The point of intersection with the vertical axis then gives the position of the metacentre.

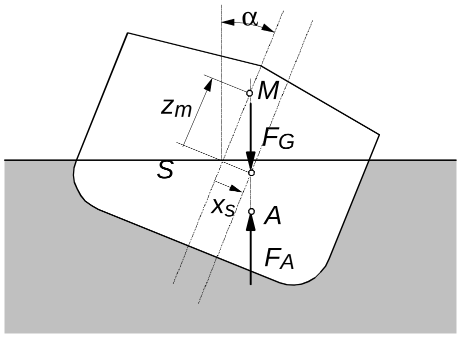


Fig. 3.5 Theoretical determination of metacentric height

With the second method of determining the metacentre, it is assumed that, given a stable heel position, dead weight F_G and buoyancy F_A have one line of action. The point of intersection of this line of action with the central axis gives the metacentre M (Fig. 3.5). The heel angle α and the lateral displacement of the centre of gravity x_S yield the following for the metacentric height z_m

$$z_m = x_s \cot\alpha$$

4 Experiments

4.1 Calculation of Centre of Gravity Position

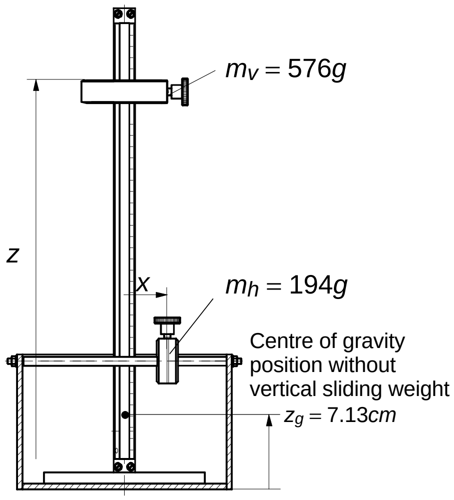


Fig. 4.1 Position and size of sliding weights

The first step is to determine the position of the overall centre of gravity x_S, z_S from the set position of the sliding weights.

The horizontal position is referenced to the centre line:

$$x_s = \frac{m_h\, x}{m + m_v + m_h} = 0.057\, x\,.$$

The vertical position is referenced to the underside of the floating body:

$$z_s = \frac{m_v\, z + (m + m_h)\, z_g}{m + m_v + m_h} = 5.924 + 0.169\, z.$$

Stability gradient:

$$\frac{d\, x_s}{d\, \alpha} = \frac{x_s}{\alpha}\,.$$

4.2 Performance of the Experiment

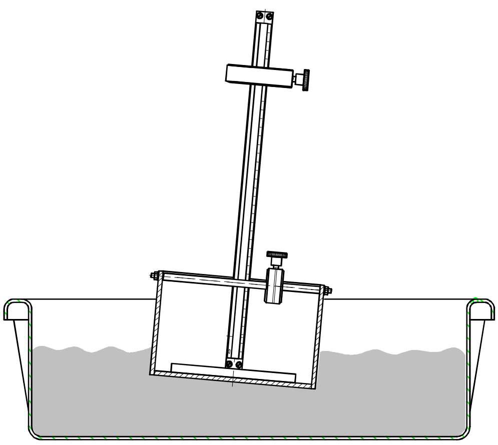


Fig. 4.2 Floating body in tank

- Set horizontal sliding weight to position x = 8cm.
- Move vertical sliding weight to bottom position.
- Fill tank provided with water and insert floating body.
- Gradually raise vertical sliding weight and read off angle on heel indicator. Read off height of sliding weight at top edge of weight and enter in table together with angle.

Position of horizontal sliding weight x = 8 cm			
Height of vertical sliding weight *z*	3 cm	6 cm	9 cm
Angle α	12.5°	16°	20.5°

4.3 Evaluation

The stated formuli are used to calculate the centre of gravity position and stability gradient and plot them on a graph.

Horizontal Position of centre of gravity x_S = 0.46 cm			
Height of vertical sliding weight *z*	3 cm	6 cm	9 cm
Centre of gravity position z_S	6.43 cm	6.94 cm	7.45 cm
Angle α	12.5°	16°	20.5°
$\frac{d x_S}{d \alpha}$	0.0368 cm/°	0.0288 cm/°	0.0224 cm/°

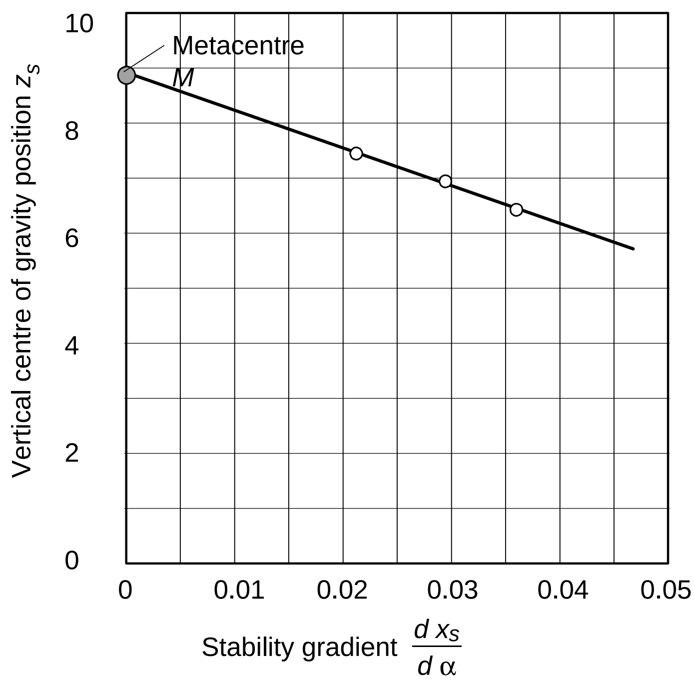


Fig. 4.3 Graphical determination of metacentre

The graphical solution yields a metacentre position of 8.9 cm above the underside of the floating body. All centre of gravity positions less than 8.9 cm result in stable floating.

As a check, the vertical sliding weight can be raised to such an extent that the metacentric height becomes negative. The floating body will then capsize. In the given case, the limit value for *z* would be 18.5 cm.

4.4 Determination of Buoyancy

A further experiment can be performed to determine buoyancy. As the floating body is block-shaped, the volume of water displaced can easily be calculated from the width, length and immersion depth. The immersion depth can be read off the vertical scale (6). A horizontal floating position is a prerequisite for this. The density ρ of the water and the acceleration due to gravity $g = 9.81\ m/s^2$ give the buoyancy:

$$F_A = B \cdot L \cdot T \cdot \rho \cdot g = F_G.$$

5 Technical Data

Floating body		
Length:	300	mm
Width:	200	mm
Height of sides:	120	mm
S Overall height	430	mm

Weights		
Floating body not including sliding weights:	Approx. 2636	g
Vertical sliding weight	576	g
Horizontal sliding weight	194	g

Centre of gravity position without vertical sliding weight

x_S (from centre)	0.00	mm
z_S (from underside)	63.6	mm

Plastic tank, capacity	50	litres