MET 335W

Stability of a Floating Vessel

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Experiment Title: Stability of a Floating Vessel

Purpose:
The purpose of this experiment is to experimentally determine the location of the metacenter of a floating vessel and compare it to the calculated theoretical value. This is by graphic analysis of the angles of tilt of the pontoon with various centers of gravity. This experiment also focuses on developing an understanding of the concept of buoyancy and how the stability of a vessel can be affected.

Theoretical Considerations:
The height of the center of gravity determines the stability of a floating body. Equilibrium orientation allows a vertical axis through the center of gravity and the center of buoyancy. Determination of the metacenter, that intersects with the vertical axis, yields a new equilibrium when the body is slightly rotated.

Description of Apparatus:
- TecQuipment Metacentric Height and Stability H2, to include:
- Rectangular floating pontoon, 360 mm x 202 mm x 76 mm
- Plastic sail with five rows of V-slots, equally spaced at 7.5 mm apart, height: 240 mm
- Adjustable weight, consisting of two machined cylinders screwed together, 388 g
- Plumb blob, suspended from the top center of the sail
- Tilt angle protractor, located at the base of the sail
- Water tank, molded plastic, 600 mm x 400 mm x 120 mm

Step-by-Step Procedure:
1. The breadth and length of the pontoon were measured and recorded on the data sheet.
2. The vessel was placed in the water tank so that it was free floating in water.
3. The depth of immersion of the vessel (distance from the bottom of the vessel to the water level) was measured and recorded on the data sheet.
4. The mass of the adjustable weight was recorded on the data sheet.
5. The mass of the entire vessel (without the adjustable weight) was added to the mass of the adjustable weight, and the total mass of the floating assembly (including the adjustable weight) was recorded on the data sheet.
6. The adjustable weight was relocated to the centerline of the bottom row of the sail.
7. The vertical height of the adjustable weight (from the centerline of the weight to the bottom of the vessel) was measured and recorded on the data sheet.
8. The adjustable weight was secured in the far left notch of the bottom row of the sail (75 mm from the center of the row).
9. The angle of tilt of the assembly (distance from the centerline of the sail) was measured on the protractor at the base of the sail, based on the location of the plumb bob string.
10. The angle of tilt was recorded on the data sheet.

11. The adjustable weight was moved over 2 notches (15 mm) and the angle of tilt was recorded on the data sheet.
12. The procedure was repeated by moving the adjustable weight 2 notches each time until it had traveled across the entire bottom row of the sail.
13. The adjustable weight was relocated to the centerline of the middle row of the sail.
14. The vertical height of the adjustable weight (from the centerline of the weight to the bottom of the vessel) was measured and recorded on the data sheet.
15. The adjustable weight was moved and secured to the far left notch of the middle row of the sail.
16. The angle of tilt of the assembly (distance from the centerline of the sail) was measured on the protractor at the base of the sail, based on the location of the plumb bob string.
17. The angle of tilt was recorded on the data sheet.
18. The adjustable weight was moved over 2 notches (15 mm) and the angle of tilt was recorded on the data sheet.
19. The procedure was repeated by moving the adjustable weight 2 notches each time until it had traveled across the entire middle row of the sail.
20. The adjustable weight was relocated to the centerline of the top row of the sail.
21. The vertical height of the adjustable weight (from the centerline of the weight to the bottom of the vessel) was measured and recorded on the data sheet.
22. The adjustable weight was moved and secured to the far left notch of the top row of the sail.
23. The angle of tilt of the assembly (distance from the centerline of the sail) was measured on the protractor at the base of the sail, based on the location of the plumb bob string.
24. The angle of tilt was recorded on the data sheet.
25. The adjustable weight was moved over 2 notches (15 mm) and the angle of tilt was recorded on the data sheet.
26. The procedure was repeated by moving the adjustable weight 2 notches each time until it had traveled across the entire top row of the sail.

Recorded Data Table:

Total mass of pontoon (without adjustable weight):	2345 g
Mass of adjustable weight:	388 g
Breadth of pontoon (B):	202 mm
Length of pontoon (L):	360 mm
Depth of immersion:	87 mm

Table 1: Angle of Tilt Caused By the Adjustable Weight Displacement

Height of adjustable weight, y_1 (mm)	**Angles of list (degrees) for adjustable weight lateral displacement from sail center line x_1 (mm)**										
	-75	**-60**	**-45**	**-30**	**-15**	**0**	**15**	**30**	**45**	**60**	**75**
87	-10.5	-8.5	-6.5	-4.5	-2.5	0	2.5	4.5	6.5	8.5	10.5
207	–	–	-9.0	-6.0	-3.25	0	3.25	6.0	9.0	–	–
327	–	–	–	–	-5.0	0	5.0	–	–	–	–

Calculations (to include sample calculations):

- Weight of Floating Pontoon, W_p 2345 g = 2.345 kgf

- Weight of Adjustable Weight, ω 388 g = 0.388 kgf

- Total Weight of Floating Assembly, W 2733 g = 2.733 kgf

  → $W = W_p + \omega$

- Volume of water displaced by Pontoon, V

  → $V = W/\gamma = 2.733/1000$ 2.73×10^{-3} m^3

- Breadth of Pontoon, B 202 mm = 0.202 m

- Length of Pontoon, L 360 mm = 0.360 m

- Area of Pontoon in plane of water surface

  → $A = LB = 0.360 \text{ m} \times 0.202 \text{ m} = 0.07272 \text{ m}^2$ 7.27×10^{-2} m^2

- Second Moment of Area, $I = \dfrac{LB^3}{12}$

  → $I = \dfrac{0.360 \times (0.202)^3}{12} = 2.47 \times 10^{-4}$ 2.47×10^{-4} m^4

- Depth of immersion $OC = \dfrac{V}{A} = \dfrac{2.733 \times 10^{-3}}{7.272 \times 10^{-2}}$ 3.76×10^{-2} m = 37.58 mm

- Theoretical Height of Metacenter above BM,

  Center of Buoyancy $= \dfrac{I}{V} = \dfrac{2.472 \times 10^{-4}}{2.733 \times 10^{-3}}$ 9.04×10^{-2} m = 90.4 mm

- Depth of Center of Buoyancy, B, above O =>,

  → $OB = BC = \dfrac{OC}{2}$, ½ depth of immersion

  → $\dfrac{37.58 \text{ mm}}{2} = 18.8 \text{ mm}$

Sample Calculations:

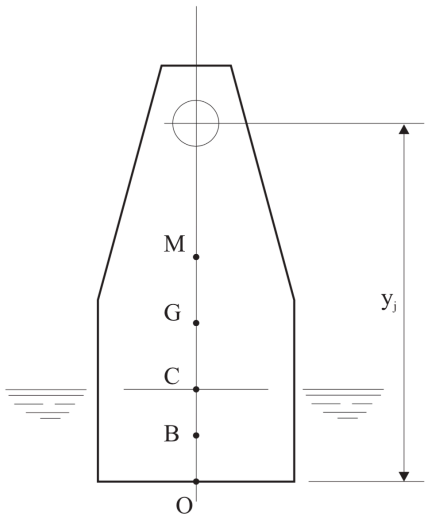


Figure 1: Height of Center of Gravity

Calculating the metacentric height:

$$GM = \frac{[\text{adjustable weight}]}{[\text{total weight of floating assembly}]} \times \text{slope (mm/rad)}$$

$$= \omega \quad (\text{Slope in mm/rad}) = \frac{(0.391 \times 402)}{2.575} = 61.0 \text{ mm}$$

$$OG = \frac{y_1 \omega}{W} + A \text{ , where A is a constant} = 40.7 \text{ mm}$$

$$= \frac{(87)(0.391)}{2.575} + 40.7 = 53.9 \text{ mm}$$

$$CG = OG - OC = 53.9 - 37.6 = 16.3 \text{ mm}$$

$$CM = GM + CG = 61.0 + 16.3 = 77.3 \text{ mm}$$

$$BM = BC + CM = 18.8 + 77.3 = 96.1 \text{ mm}$$

Calculated Data Table:

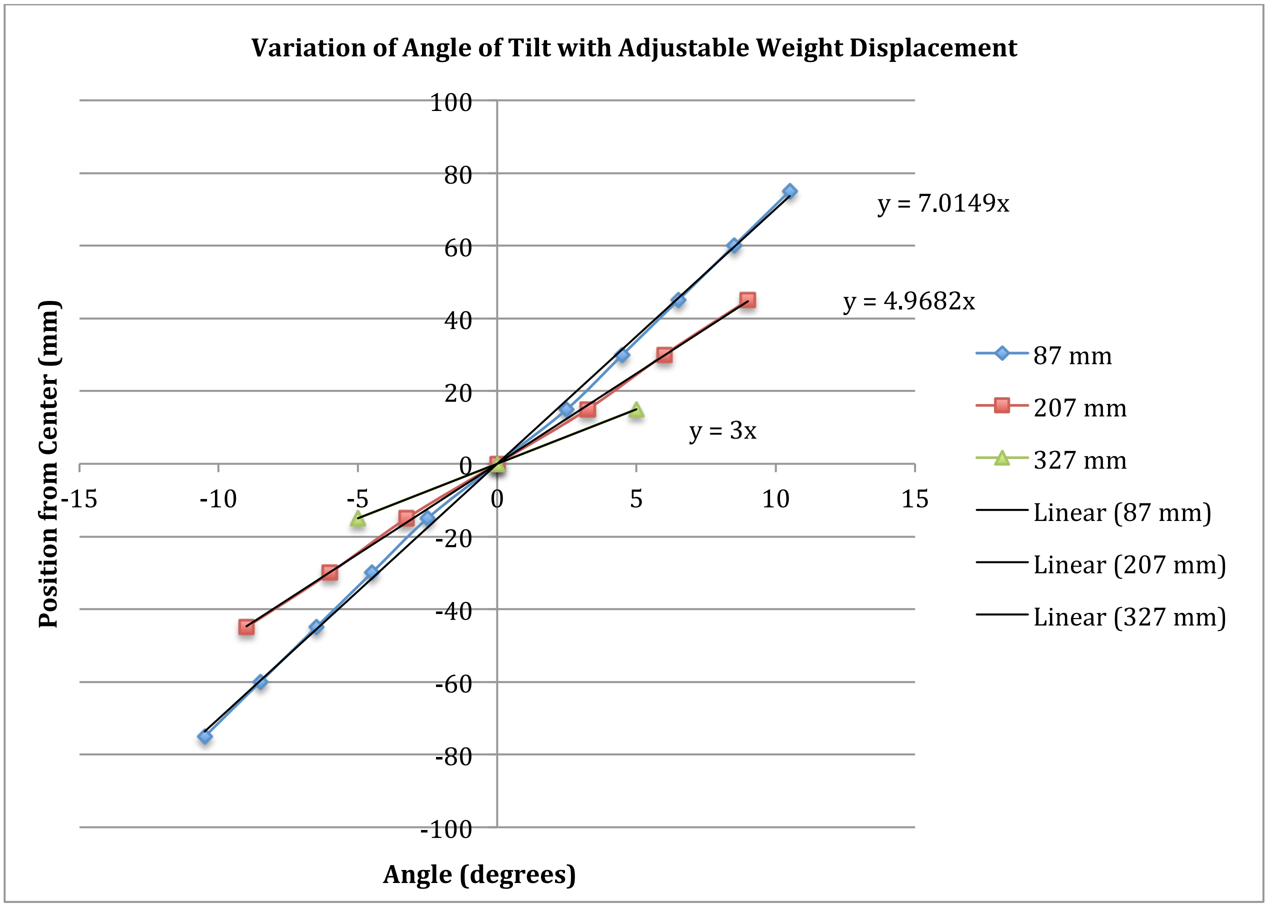
Table 2: Experimentally Derived Metacentric Height

Height of the Adjustable Weight (mm)	Slope from Graph 1	Conversion to mm/rad (1 mm/degree = 57.3 mm/rad)	Experimental Metacentric Height, GM (mm)	Pontoon Base to Center of Gravity, OG (mm)
87	7.01	402	61.0	53.9
207	4.97	285	43.3	72.1
327	3.00	172	26.1	90.3

Height of the Adjustable Weight (mm)	Height of Center of Gravity Above the Water Surface, CG (OC = 37.6 mm)	Height of M above the water, CM (mm)	Metacenter Height Above the Center of Buoyancy, BM (mm)*
87	16.3	77.3	96.1
207	34.5	77.8	96.6
327	52.7	78.8	97.6

*** Average BM = 96.8 mm**

Graph 1: Variation of Angle of Tilt With Adjustable Weight Displacement



Discussion of Results and Conclusions:

Stability of the floating vessel was shown to depend on its metacentric height, GM, with respect to the center of gravity, CG, and center of buoyancy, BM. By changing the center of gravity of the pontoon, the center of buoyancy moved and torqued the floating vessel back to its original position.

When the metacenter lies below the center of gravity, the result of the couple is to increase the angular displacement and the pontoon is unstable. The theoretical metacentric height is independent of the vertical height of its center of gravity. The theoretical distance of the metacentric height from the center of buoyancy is only a function of its second moment of inertia at the water line and the displaced volume. Neither of these depends on the vertical location of the center of gravity.

Graph 1, Variation of Angle of Tilt With Adjustable Weight Displacement, helped illustrate the relationship between the center of gravity, the center of buoyancy, and the metacenter. For a floating vessel to remain stable, its center of gravity must be below its metacenter. When the metacenter is less than the center of gravity, the vessel is prone to tipping or rolling. As shown in Graph 1, for each change of adjustable weight there was a coinciding angle of tilt. Using the gradients of the lines or slope, the metacentric height was able to be determined for the three vertical height locations. Each location provided a metacentric height that was above the center of gravity.

The average experimental center of buoyancy (BM) for the three vertical height locations was 96.8 mm. Center of buoyancy depends only on the total weight of the pontoon and is independent of the adjustable weights. The computed theoretical value was 90.4 mm, giving a 7.1 % error rate.

Movement of the plumb bob could be considered a source of error due to swinging and being an indicator for the angle of list. Human error in reading the angle of list for the adjustable weight lateral displacement should also be considered. Automation could improve accuracy and precision.