

Loading the Barge Lowers Its Stability with the Centre of Gravity Never Moved

— **1.1667** m at a draft of **2** m falls to **0.0825** m at **4.0825** m, a factor of **14.1** — that is the minimum, and beyond it stability rises again — at the minimum **KB** and **BM** are exactly equal — [Paper 393]

Yuuki YAMAGISHI (山岸 勇輝)

Yamagishi Complexity Torus Lab, Japan

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— *From thinking to syncing.* —

Abstract

“Stow the heavy things low and the ship will be stable”, the saying goes. This paper shows that the righting arm can be cut by a factor of 14.1 without moving the centre of gravity at all—the only thing increased is the amount of cargo. No new theorem or law is claimed. First, $GM = KB + BM - KG$, where $BM = B^2/(12d)$ goes as the square of the beam and inversely with the draft (Section 1). Second, widening the beam by 20 per cent takes GM from 1.1667 to **3.0000** m (Section 2). Third, and this is the core of the paper. Deepening the draft with the centre of gravity fixed lowers GM , reaching a minimum of **0.0825** m at **4.0825** m (Section 3). Fourth, at that minimum **KB** and **BM** are exactly equal, both **2.041241** m (Section 3). Fifth, widening the beam by 20 per cent is **1.8333** times as effective as lowering the centre of gravity by a whole metre (Section 2). Sixth, the separator is whether one moves the height of the centre of gravity or the shape of the waterplane (Section 5).

Scope of this paper (scope note): No new theorem or law is claimed—metacentric height, $BM = I/V$ and initial stability theory are all known in naval architecture. No ship is designed—stability criteria and subdivision for real vessels are not given. Only one box-shaped model is examined. Large angles are not treated— GM is the righting stiffness at small heel; large angles require the righting-arm curve. Only initial stability is examined. Free-surface effect is not treated—the apparent rise in the centre of gravity from shifting liquid cargo is not the subject. Dynamics are not treated—roll period and resonance are not the subject. Only static equilibrium. A box shape is assumed—a real waterplane is not rectangular and the BM formula needs correction; the qualitative direction does not change. Relation to earlier papers: Paper 357 showed that maximum power and maximum efficiency are different points—here a sum of two terms has an interior minimum. Paper 385 showed that a product of two monotone factors has an interior maximum—here a sum has an interior minimum. Paper 386 showed that the rate moves with the solubility fixed—here the stability moves with the centre of gravity fixed. Paper 300 showed that same-root and different-root can be decided—the height of the centre of gravity and the shape of the waterplane are different-root by that criterion. What is added is putting numbers on GM under four operations, locating the minimum at $B/\sqrt{6} = 4.082483$ m with value 0.082483 m, showing that $KB = BM$ holds exactly there, obtaining the 1.8333 advantage of widening, and placing the separator at “centre of gravity or waterplane”.

1. Notation and the Question

Setting: take a box-shaped barge of beam B and draft d , with the centre of gravity at height KG .

$$GM = \underbrace{\frac{d}{2}}_{KB} + \underbrace{\frac{B^2}{12d}}_{BM} - KG$$

Positive GM rights the vessel; negative capsizes it. The baseline below is $B = 10$ m, $d = 2$ m, $KG = 4$ m.

Observation 1.1

KG enters as a single subtracted term. Nothing but a subtraction—lower it by one metre and GM rises by exactly one metre.

Observation 1.2

B enters squared. $BM = B^2/(12d)$ —widen the beam by 20 per cent and BM grows by 44 per cent.

Observation 1.3

d enters the two terms in opposite senses. Positively in KB , reciprocally in BM —deepen the draft and one rises while the other falls.

Question: to make a ship stable, what should be moved?

2. Widening the Beam Beats Lowering the Centre of Gravity

Computation 2.1: operations from the baseline $B = 10$, $d = 2$, $KG = 4$ (computed in this paper).

Operation	GM [m]	Change
(baseline)	1.1667	—
Widen the beam 20 per cent ($B = 12$)	3.0000	+1.8333
Lower the centre of gravity 1 m ($KG = 3$)	2.1667	+1.0000
Deepen the draft 1 m ($d = 3$)	0.2778	−0.8889
Deepen the draft 3 m ($d = 5$)	0.1667	−1.0000

Observation 2.2

widening the beam 20 per cent is 1.8333 times as effective as lowering the centre of gravity a whole metre. +1.8333 against +1.0000—because the beam enters squared.

Observation 2.3

doubling the beam multiplies BM by exactly four. $4.1667 \rightarrow 16.6667$ —the square confirmed numerically.

Observation 2.4

doubling the draft halves BM exactly. $4.1667 \rightarrow 2.0833$ —the reciprocal confirmed numerically.

Observation 2.5

the bottom two rows do not move the centre of gravity at all. KG stays at 4—and GM falls anyway.

3. The Minimum Is 0.0825 m at 4.0825 m, Where KB Equals BM

Computation 3.1: GM against draft at $B = 10$, $KG = 4$ (computed in this paper).

Draft d [m]	KB [m]	BM [m]	GM [m]
2.0000	1.0000	4.1667	1.1667
3.0000	1.5000	2.7778	0.2778
4.0000	2.0000	2.0833	0.0833
4.0825	2.0412	2.0412	0.0825
5.0000	2.5000	1.6667	0.1667
6.0000	3.0000	1.3889	0.3889
8.0000	4.0000	1.0417	1.0417

Observation 3.2

this is the core of the paper. Without moving the centre of gravity at all, GM falls from 1.1667 m to 0.0825 m, a factor of **14.1**—the only thing increased is the cargo, and KG stays at 4 m.

Observation 3.3

at the minimum KB and BM are exactly equal. Both 2.041241 m—solving $d/2 = B^2/(12d)$ gives $d = B/\sqrt{6}$, which is 4.082483 m.

Observation 3.4

beyond it the stability rises again. 0.1667 at $d = 5$, 1.0417 at $d = 8$ —it does not degrade monotonically; there is a valley.

Observation 3.5

the valley is not shallow but deep. 0.0825 m would be a dangerous figure for a real vessel—somewhere on the way through lies the most dangerous draft.

Observation 3.6

the shape is the inverse of Paper 385. There a product of two monotone factors had an interior maximum—here a sum of two monotone terms has an interior minimum. In both, the extremum stands partway rather than at an endpoint.

4. Why GM Moves Although KG Does Not

Observation 4.1

GM is a relation between the centre of gravity and the centre of buoyancy, not a quantity of the centre of gravity alone. KB and BM both come from the hull form—fix KG and those two still move.

Observation 4.2

$BM = I/V$. I is the second moment of the waterplane, V the displaced volume—add cargo and V grows while I does not.

Observation 4.3

so BM falls. Only the denominator grows—in a box the beam at the waterline does not change as it sinks, so I is constant.

Observation 4.4

KB rises, but not fast enough. The slope of $d/2$ is one half—and the fall of BM , $B^2/(12d^2)$, exceeds it while $d < B/\sqrt{6}$.

Observation 4.5

they are different-root by the criterion of Paper 300. KG is set by the stowage, BM by the waterplane and the displacement—two things with different roots stand behind one word, “stability”.

5. Separator: The Height of the Centre of Gravity, or the Shape of the Waterplane

Observation 5.1

separator—did the cargo move up or down, or did its amount increase.

Operation	KG	BM	GM
Restow the same load lower	falls	unchanged	rises
Add load at the same height	unchanged	falls	falls
Widen the beam	unchanged	rises squared	rises sharply

Observation 5.2

the second row is the counterintuitive one. The centre of gravity has not moved and things get worse—“keep the centre of gravity low” cannot explain it.

Observation 5.3

the third row is the most effective. +1.8333—though the beam is not a quantity one can change freely.

Observation 5.4

the separator can be tested. Add cargo at the same centre of gravity height and run an inclining experiment — GM falls.

Observation 5.5

to be honest — both 0.0825 m and 4.082483 m come from a box model with a rectangular waterplane. A real hull narrows fore and aft, so I varies with draft — what does not move is that KB and BM move in opposite senses, and that they coincide at the minimum.

Observation 5.6

one last thing — “lower the centre of gravity and the ship will be stable” is correct. Correct, and it names the least effective of the quantities one can move — a correct remedy is not necessarily the best one.

6. Roll Call and Closing

1. $GM = KB + BM - KG$ (Section 1): KG is only subtracted.
2. +1.8333 for a 20 per cent beam (Computation 2.1): 1.8333 times a metre of KG .
3. Double the beam, four times BM (Observation 2.3): the square.
4. Double the draft, half the BM (Observation 2.4): the reciprocal.
5. 1.1667 m down to 0.0825 m (Computation 3.1): a factor of 14.1.
6. KG stays at 4 m (Observation 3.2): the centre of gravity never moved.
7. $KB = BM = 2.041241$ at the minimum (Observation 3.3): $d = B/\sqrt{6}$.
8. Beyond it, stability rises (Observation 3.4): there is a valley.
9. $BM = I/V$ with only V growing (Observation 4.2): I is constant.
10. A correct remedy is not the best one (Observation 5.6): the beam matters more.

Closing: “stow the heavy things low and the ship will be stable”, the saying goes — yet the righting stiffness can be cut by a factor of 14.1 without moving the centre of gravity at all. Initial stability is $GM = KB + BM - KG$, with $KB = d/2$ and $BM = B^2/(12d)$ — KG is nothing but a subtracted term, so lowering it a metre raises GM by exactly a metre. The beam enters squared: double it and BM becomes exactly four times as large (

4.1667 → 16.6667). The draft enters the two terms oppositely, raising KB and lowering BM . So widening the beam beats lowering the centre of gravity—from the baseline $GM = 1.1667$ m ($B = 10$ m, $d = 2$ m, $KG = 4$ m), a 20 per cent wider beam gives **3.0000** m (+1.8333) while a whole metre of KG gives 2.1667 m (+1.0000)—a factor of **1.8333**. Because the beam enters squared. And deepening the draft with the centre of gravity fixed lowers GM —with KG held at 4 m, it falls from 1.1667 m to **0.0825** m at a draft of 4.0825 m. At that minimum KB and BM are exactly equal, both **2.041241** m—solving $d/2 = B^2/(12d)$ gives $d = B/\sqrt{6} = 4.082483$ m. Beyond it stability rises again, 0.1667 at $d = 5$ and 1.0417 at $d = 8$: not a monotone decline but a valley. The valley is not shallow—0.0825 m would be a dangerous figure for a real vessel, so somewhere on the way through lies the most dangerous draft. It is the inverse of Paper 385, where a product of two monotone factors had an interior maximum; here a sum has an interior minimum. GM moves although KG does not, because GM is not a quantity of the centre of gravity alone— $BM = I/V$, and adding cargo grows the displaced volume V while the waterplane moment I stays constant, since a box does not widen as it sinks. Only the denominator grows, so BM falls. KB rises with slope one half, and the fall of BM , $B^2/(12d^2)$, exceeds it while $d < B/\sqrt{6}$. By the criterion of Paper 300 they are different-root: KG is set by the stowage, BM by the waterplane and the displacement. One thing does the separating—did the cargo move up or down, or did its amount increase. Restow the same load lower and KG falls so GM rises; add load at the same height and KG is unchanged while BM falls, so GM falls. “Keep the centre of gravity low” cannot explain the second case. It can be tested: add cargo at the same centre of gravity height and run an inclining experiment, and GM falls. To be honest—both 0.0825 m and 4.082483 m come from a box model with a rectangular waterplane, and a real hull narrows fore and aft so I varies with draft. What does not move is that KB and BM move in opposite senses, and that they coincide at the minimum. One last thing—“lower the centre of gravity and the ship will be stable” is correct. Correct, and it names the least effective of the quantities one can move. A correct remedy is not necessarily the best one.

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Yuuki YAMAGISHI (山岸 勇輝)

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