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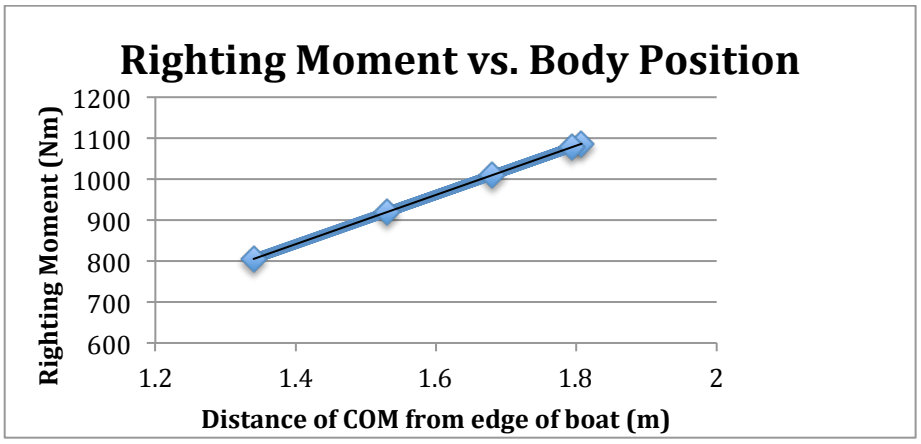
Righting Moment in the 29erXX

How much can righting moment realistically vary?

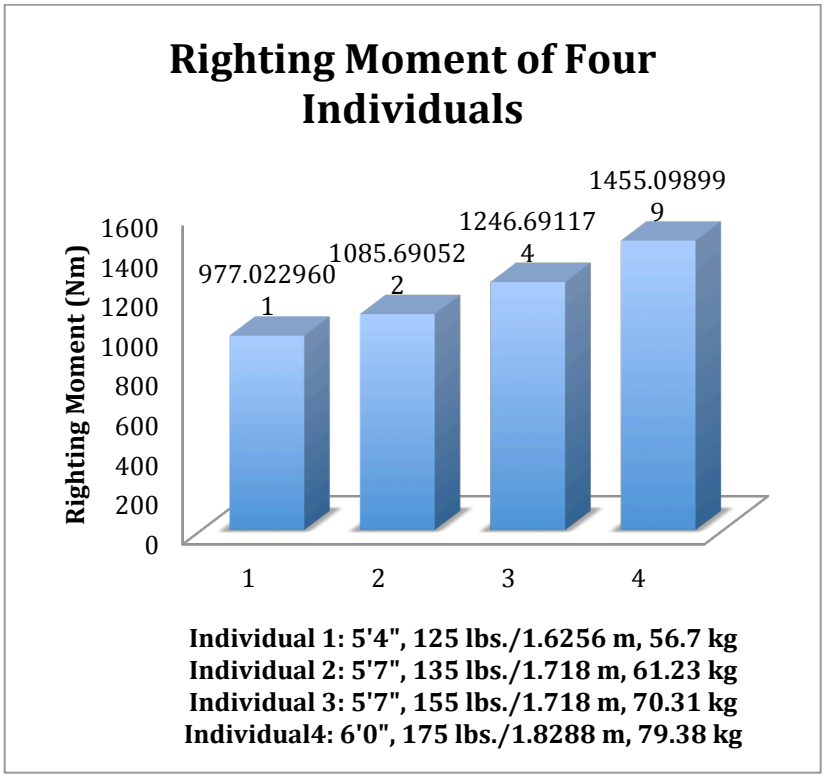
It is well known that heavier sailors can go faster in wind due to their increased righting moment. I wanted to figure out how much righting moment varies between different heights and weights of sailors and how much righting moment is affected when a sailor raises or lowers the angle between their body and the water (the body angle).

I made a few simplifying assumptions. Most importantly, I modeled the system as planar and neglected the righting moment of the centerboard. I also used an average center of mass to height ratio of 0.5515.[1] I used Excel to do my calculations and create the graphs.

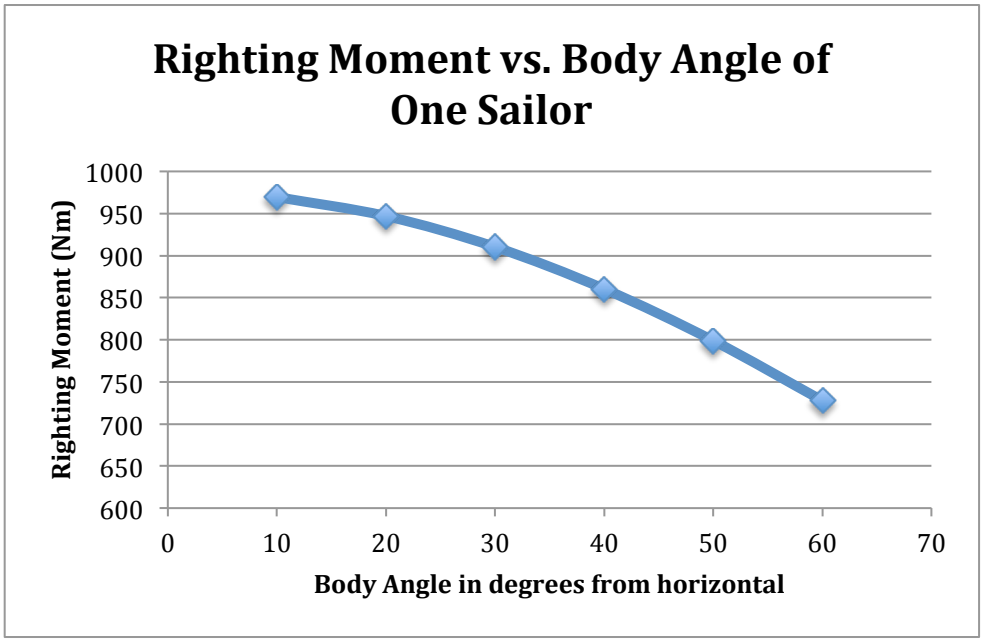
Not surprisingly, there is a linear relationship between the righting moment and weight or height of a sailor. Combining these factors makes things more interesting.



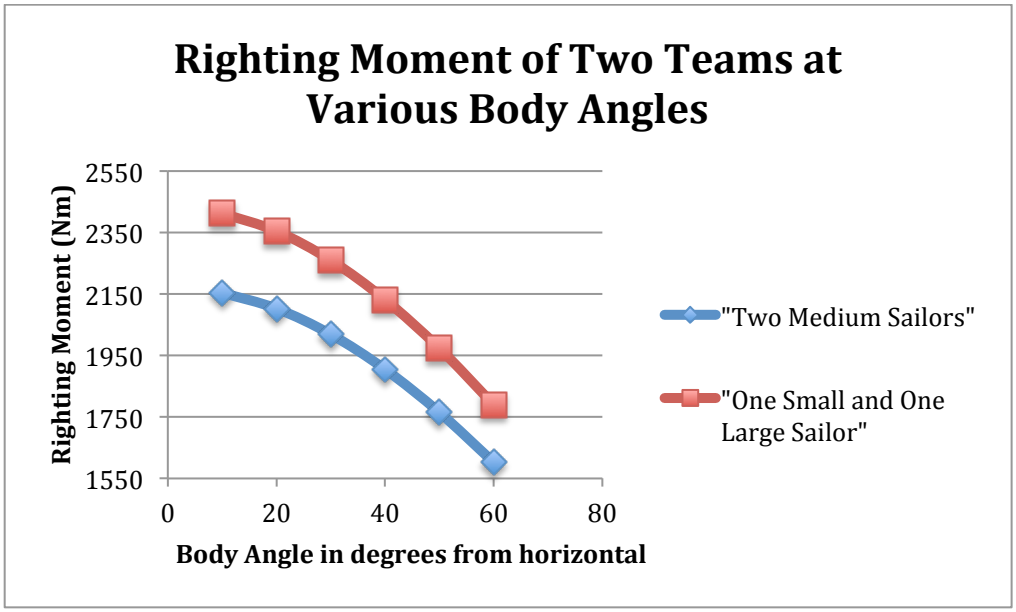
For example, I found were that although a 6'0", 175 lb. sailor weighs 40% more than a 5'4", 125 lb. sailor, they actually have 50% more righting moment due to their increased distance of the COM from the edge of the boat.



However, the relationship between righting moment and the body angle of a sailor is not linear. With every 10 degrees that a sailor toggles up, their righting moment decreases more than the previous 10 degree change (i.e. the difference in righting moment between being toggled up 20 and 30 degrees is greater than the difference between 10 and 20 degrees. I had never thought of this before.



From that we can also deduce that a heavier sailor's righting moment will decrease proportionally but its value will decrease faster (i.e. a steeper downward curve) than that of a smaller sailor.



In this graph, the two medium sailors are 5'7", 135 lbs each. The small and large sailor team consists of one 5'4", 125 lb sailor and one 6'0", 175 lb sailor.

Assumptions

- Rigid bodies
- Planar system in equilibrium
- Neglect righting moment of centerboard
- Center of mass for each position is an estimate
- Neglect weight of boat (symmetrical when excluding crew weight)

Variables

- Weight & height of skipper
- Weight & height of crew
- Body position

Boat Dimensions

- Length: 4.42 m (14'6")
- Width: 1.72 m (5'8")
- Height: 6.60 m (21'8")
- Recommended combined crew weight: 120 kg (265 lbs)

Note: this was a project for a statics engineering class at Stanford University.

Sources

Elert, Glenn. "Center of Mass of a Human." The Physics Factbook. 2006. Accessed 11 Mar 2012.
<http://hypertextbook.com/facts/2006/centerofmass.shtml>.

Bethwaite, Julian. Personal Interview. 6 Mar 2012.

Watin, Simon. *Internship Report: 49er Performance Enhancement.* Ecole Polytechnique. 2007.
<http://9eronline.com/library/49er%20Performance%20Enhancement%20Report%20by%20Simon%20Watin.pdf>.
A Bethwaite Design intern's report, very comprehensive. It has a great section on weight and how by analyzing the speed advantage of heavier crews, they decided to scale down the size of the mast in order to reach optimal levels for the target crew weight for the boat.

"29er Dimensions." Bethwaite Design.
<http://bethwaite.com/designs/29erXX.html>. Accessed 11 Mar 2012.

Bethwaite, Frank. *Higher Performance Sailing.* Adlard Coles: 2008. Print.