Amphibious Vehicle Buoyancy Modeling

1. Summary

Several different attributes make up the amphibious context model but the main results are reserve buoyancy, range and stability. An excel spreadsheet was put together to contain all of these results based on inputs of a vehicle's basic dimensions and weight information. An example vehicle was chosen in order to prove out the calculations; this example was created using Pro/engineer and basic information from a public domain website, Hydrotek.

1.1 Technical Challenges

Assumptions were made for some of the calculations. First for any vehicle chosen, the results are in relation to the example vehicle unless specific values are known. Since exact volume and mass values are not always known this information can be set as a relation to the initial example vehicle that was used. Another assumption is that the area used for the stability curve calculation was a bounding box instead of the actual geometric shape of the vehicle. This allows for simple calculations that can be done quickly and higher powered tools such as CFD are not needed. As long as max width and height are known a quick check on the stability of the vehicle can be done.

1.2 General Methodology

In order to determine the reserve buoyancy, range and stability of an amphibious vehicle within a water condition an example vehicle was chosen. The example vehicle is a commercial amphibian (hydrotrek) whose weight and dimensional values are obtainable to the public online. This vehicle was set up within Pro/Engineer and created in such a way that the major dimensions were parameterized. Any change to one of the parameters will adjust the rest of the model through relation calculations. This allows for several size conditions to give the outputs needed for the buoyancy and stability calculations. The inputs needed are length, width, height, wheel diameter and either 2 or 4 occupants. The outputs produced are total volume, center of gravity, and vehicle mass. Again these outputs are based on relations to the initial model.

Once the outputs are obtained, either through the Pro/e model or direct inputs, visual basic code is utilized to determine the reserve buoyancy, range and stability of the model.

Table 1: Example Vehicle Inputs and Outputs

Inputs:	Max width	2451.1	mm
	Max length	3810	mm
	Max height	2082.8	mm
	wheel diameter	608	mm
	2 or 4 persons	4	
Outputs:	Volume	5.20E+09	mm^3
Center of Gravity (mm)	x	y	z
	0.00	2117.65	798.86

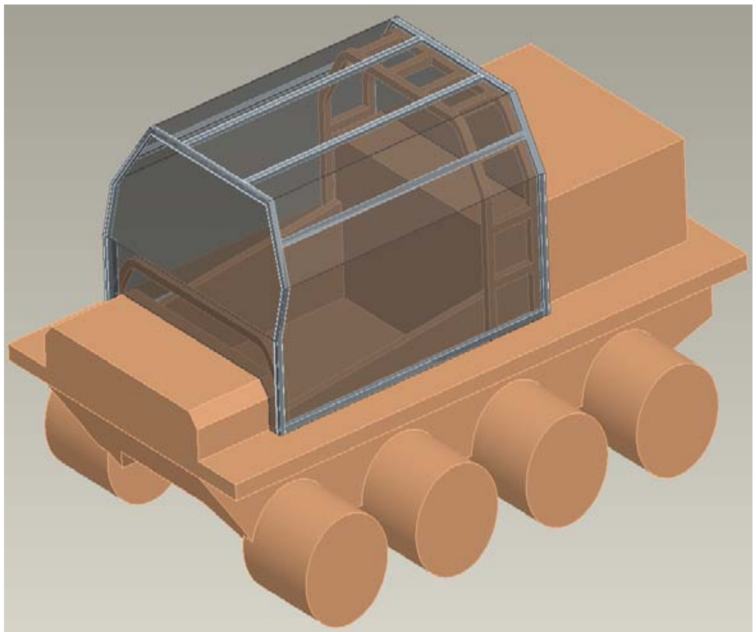

Figure 1: Pro/Engineer model of the Hydrotek vehicle

1.2.1 Reserve Buoyancy

For the buoyancy calculations fluid type, temperature and elevation can be adjusted or can be left as the baseline values. Along with reserve buoyancy several other outputs are calculated including fluid density, object density, buoyant mass and buoyant force. The reserve buoyancy is the percentage of the vehicle which remains above water therefore as long as the value is positive the vehicle will float. When the value is negative the vehicle will be completely submerged under the water.

Table 2: Baseline values for Reserve Buoyancy Calculations of the Example Vehicle

Inputs:	Object Mass	3179.4	kg	7009.3	lb
	Object Volume	5.2	m^3	183.6	ft^3
	Fluid	Fresh Water			
	Temperature	4	ºC	39.2	ºF
	Elevation	0	m	0	ft
Outputs:	Fluid Density	1000.0	kg/m^3	62.4	lb/ft^3
	Object Density	611.4	kg/m^3	38.2	lb/ft^3
	Buoyant Mass	-2021	kg	-4454.6	lb
	Buoyant Force	31190	N	7012.1	lbf
	Reserve Buoyancy	38.9	%		

The amount of particulates and debris within the fluid that the vehicle is entering can also affect the buoyancy results. If there is a large enough percentage of mud, sand, clay, gravel, etc. than the density of the mixture is changed and thus the buoyancy of whatever object rests on that mixture changes as well. Therefore coding was developed to allow for a mixture to be used and several given particulates are available to choose from. If a different substance is desired the density is required to complete the calculations.

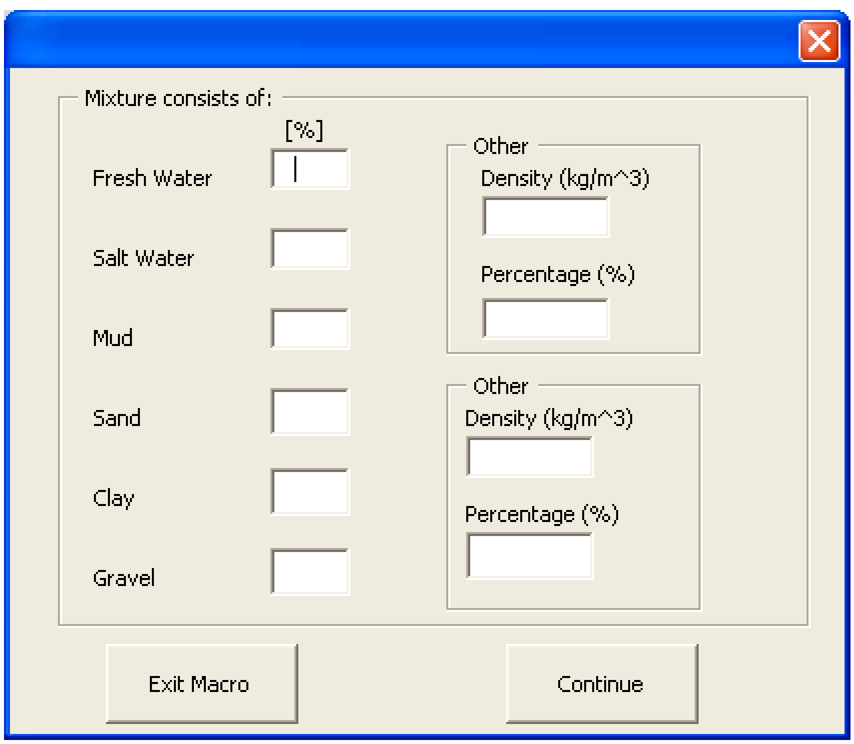

Figure 2: Mixture options

1.2.2 Range

In order to calculate the range and maximum speed of the amphibious vehicle within the water several inputs are needed. These include, fuel efficiency, fuel tank capacity, run time, power, drag coefficient and reference area. A table is provided for several different frontal geometry configurations to estimate the drag coefficient. Range is given in both miles and nautical miles and speed is given in miles per hour as well as knots.

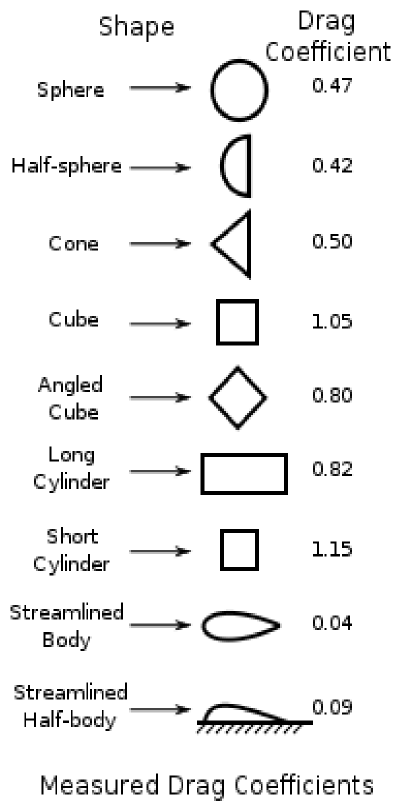

Figure 3: Drag Coefficients Values

Table 3: Baseline values for the Range Calculations of the Example Vehicle

Inputs:	Fuel Efficiency		MPG		
	Fuel Tank Capacity	10.5	gal		
	Run time	12.0	hr		
	Power	74.0	HP		
	Drag Coefficient	1.05			
	Reference Area	0.56	m^2		
Outputs:	Range	145.3	miles	126.3	Naut miles
	Max Speed	12.1	MPH	10.5	Knotts

1.2.3 Stability

The stability of the model is determined by using the weight, center of gravity and the reserve buoyancy of the vehicle in self righting calculations. The calculations use the maximum width and height of the vehicle as a bounding box in order to quickly maintain a result instead of using a more accurate depiction of the geometry.

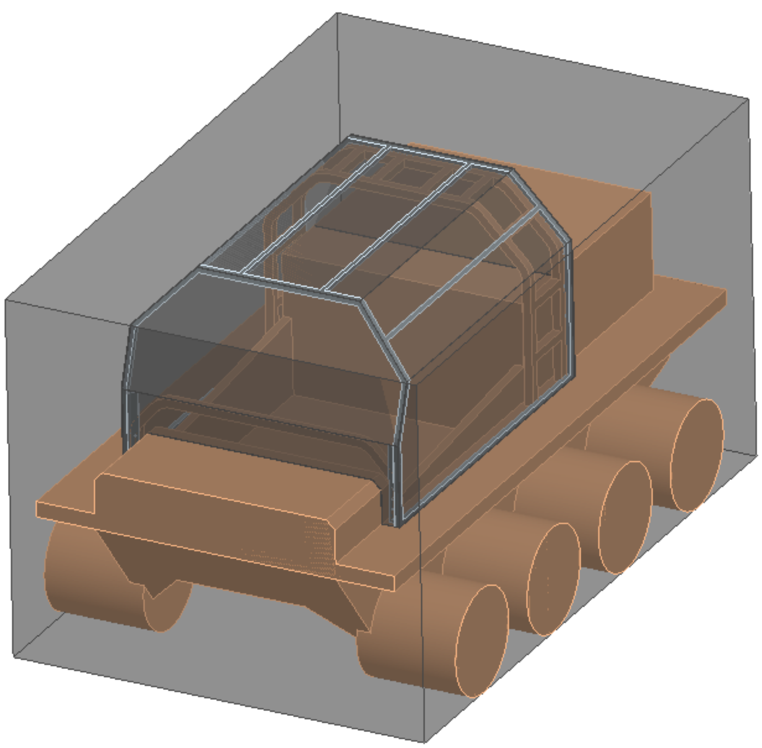

Figure 4: Bounding Box

The center of buoyancy is first determined at each tilt angle and then the perpendicular distance from the center of gravity to the center of buoyancy is calculated. The results are then graphed verse the tilt angle to form the stability curve. The stability curve shows at any particular heel angle, or angle at which the vehicle is tilted in the water, the likelihood that the vehicle will right itself or will tip over. If the slope of the curve is positive at the angle of interest than the vehicle will right itself back to equilibrium. If the slope is negative the angle will continue to increase and the vehicle will tip over. The higher the righting arm value, the more difficult, or the more force is required to tip as well.

Table 4: Righting Arm and Center of Buoyancy at each Heel Angle for the baseline vehicle

Stability Curve		Center of Buoyancy	
Heel Angle (deg)	Righting Arm (mm)	X (mm)	Y (mm)
0	0	1225.55	636.3
10	41.1	1156.181	642.4158
20	87.9	1082.359	662.3585
30	148.2	998.413	701.8687
40	222.5	907.1746	765.67
50	282.4	833.8081	838.8575
60	307.6	789.0677	902.0399
70	302.9	764.826	953.5452
80	279	752.5834	998.8378
90	242.5	748.8165	1041.4
100	198.6	752.5884	1083.962
110	152.9	764.8445	1129.253
120	112.5	789.1062	1180.753
130	89.1	833.8715	1243.923
140	89.2	907.1746	1317.13
150	94.3	998.4004	1380.963
160	78	1082.356	1420.456
170	43.1	1156.18	1440.388
180	0	1225.55	1446.5

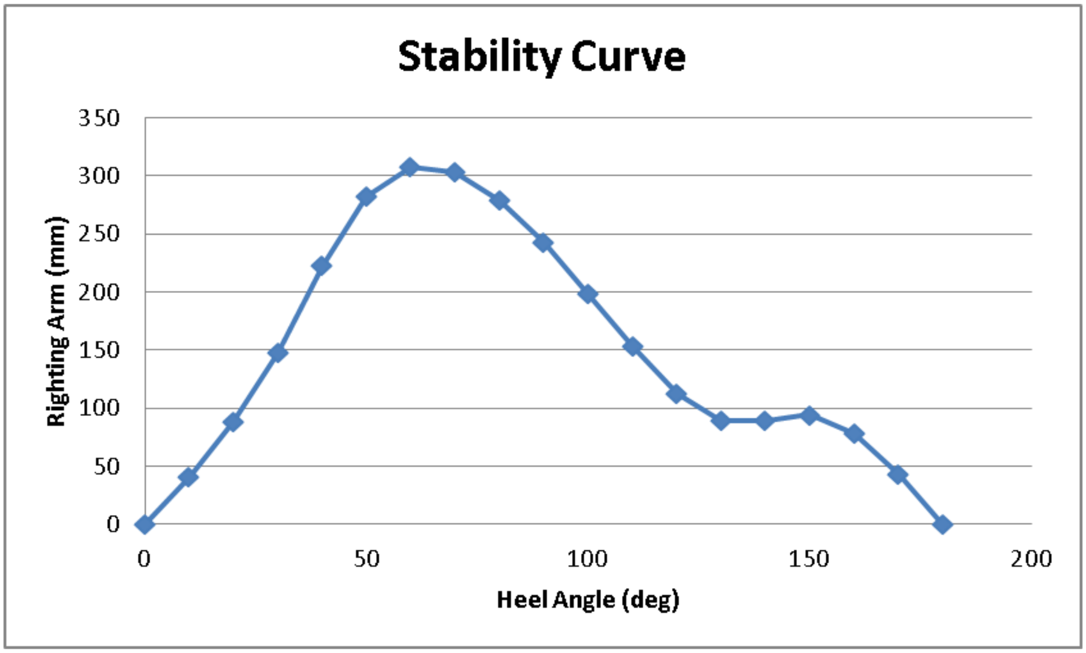

Figure 5: Stability Curve of the Baseline Vehicle

The static attitude, or pitch angle of the vehicle is also determined and is based on the length of the vehicle and the center of gravity location in relation to that length.

The static attitude, or tilt angle, of the vehicle in the water is: 15 degrees.

Figure 6: Static Attitude of the Baseline Vehicle

1.3 Technical Results

In comparison with the baseline values several different scenarios are shown below for reserve buoyancy, range and stability to show the effects of changing one or more of the parameters used.

1.3.1 Reserve Buoyancy

As can be seen in table 5 through 8, changing the temperature and elevation do not affect the reserve buoyancy by very much but the changes in fluid can. A slight increase in the reserve buoyancy is seen when using salt water as opposed to fresh water. But an even higher increase results when the fluid is a mixture. The mixture used in the results of table 8 was 75% fresh water and 25% mud. The increase in density from the addition of the mud raised the reserve buoyancy by almost 10%. This means that a vehicle in only fresh water will sit lower in the water than if the water has a mixture of mud in it as well. The positioning of the vehicle in the water affects the stability which is shown further in the report.

Table 5: Change in Fluid Type Effects on Baseline results

Inputs:	Object Mass	3179.4	kg	7009.3	lb
	Object Volume	5.2	m^3	183.6	ft^3
	Fluid	Salt Water			
	Temperature	4	ºC	39.2	ºF
	Elevation	0	m	0	ft
Outputs:	Fluid Density	1030.0	kg/m^3	64.3	lb/ft^3
	Object Density	611.4	kg/m^3	38.2	lb/ft^3
	Buoyant Mass	-2177	kg	-4798.5	lb
	Buoyant Force	31190	N	7012.1	lbf
	Reserve Buoyancy	40.6	%		

Table 6: Change in Temperature Effects on Baseline results

Inputs:	Object Mass	3179.4	kg	7009.3	lb
	Object Volume	5.2	m^3	183.6	ft^3
	Fluid	Fresh Water			
	Temperature	20	ºC	68	ºF
	Elevation	0	m	0	ft
Outputs:	Fluid Density	996.8	kg/m^3	62.2	lb/ft^3
	Object Density	611.4	kg/m^3	38.2	lb/ft^3
	Buoyant Mass	-2004	kg	-4418.0	lb
	Buoyant Force	31190	N	7012.1	lbf
	Reserve Buoyancy	38.7	%		

Table 7: Change in Elevation Effects on Baseline results

Inputs:	Object Mass	3179.4	kg	7009.3	lb
	Object Volume	5.2	m^3	183.6	ft^3
	Fluid	Fresh Water			
	Temperature	4	ºC	39.2	ºF
	Elevation	10000	m	32800	ft
Outputs:	Fluid Density	1000.0	kg/m^3	62.4	lb/ft^3
	Object Density	611.4	kg/m^3	38.2	lb/ft^3
	Buoyant Mass	-2021	kg	-4454.6	lb
	Buoyant Force	31190	N	7012.1	lbf
	Reserve Buoyancy	38.9	%		

Table 8: Effects of a fluid mixture on Baseline results

Inputs:	Object Mass	3179.4	kg	7009.3	lb
	Object Volume	5.2	m^3	183.6	ft^3
	Fluid	Mixture			
	Temperature	4	ºC	39.2	ºF
	Elevation	0	m	0	ft
Outputs:	Fluid Density	1182.5	kg/m^3	73.8	lb/ft^3
	Object Density	611.4	kg/m^3	38.2	lb/ft^3
	Buoyant Mass	-2970	kg	-6546.8	lb
	Buoyant Force	31190	N	7012.1	lbf
	Reserve Buoyancy	48.3	%		

1.3.2 Range

There are several different inputs that can affect the range and speed outputs of a vehicle but in this case the effects of the drag coefficient were focused on. As the drag decreases, the number of miles the vehicle can cross and the speed at which it can do so both increase.

Table 9: Change in Drag Coefficient Effects on Baseline Results

Drag Coefficient	Range (naut miles)	Speed (knotts)
1.05	133.6	11.1
0.9	140.6	11.7
0.75	149.4	12.5
0.6	160.9	13.4
0.45	177.1	14.8
0.3	202.8	16.9
0.15	255.5	21.3

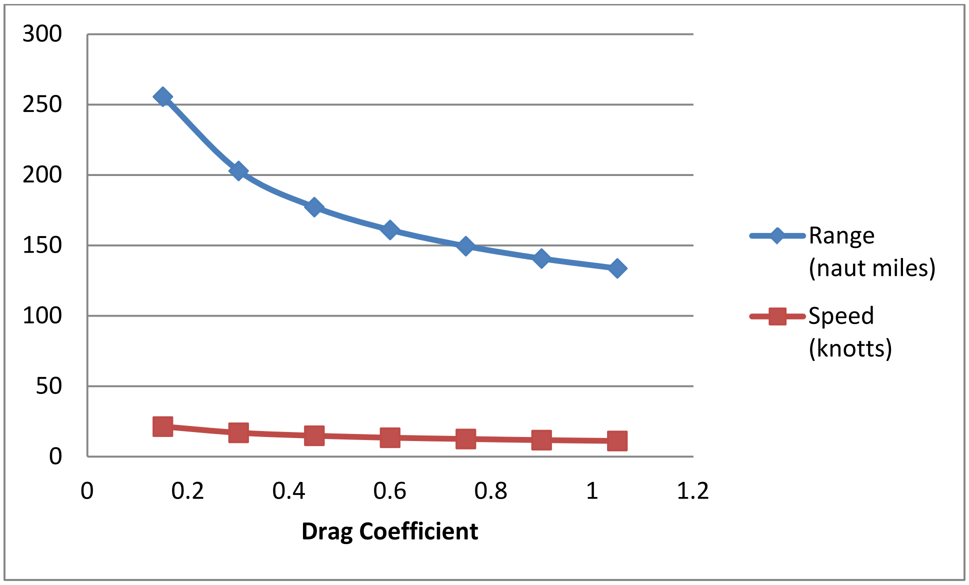

Figure 7: Effects of Drag Coefficient on Range and Speed

1.3.3 Stability

There are many different scenarios for the stability curve. Several of these are shown in the following figures. The baseline values of the bounding box are that the height is equal to 1082.8mm and the width is equal to 2451.1mm. The reserve buoyancy is 38.9% and the center of gravity height is equal to 798.86mm. Using these baseline values and changing only one per scenario gives very different curves.

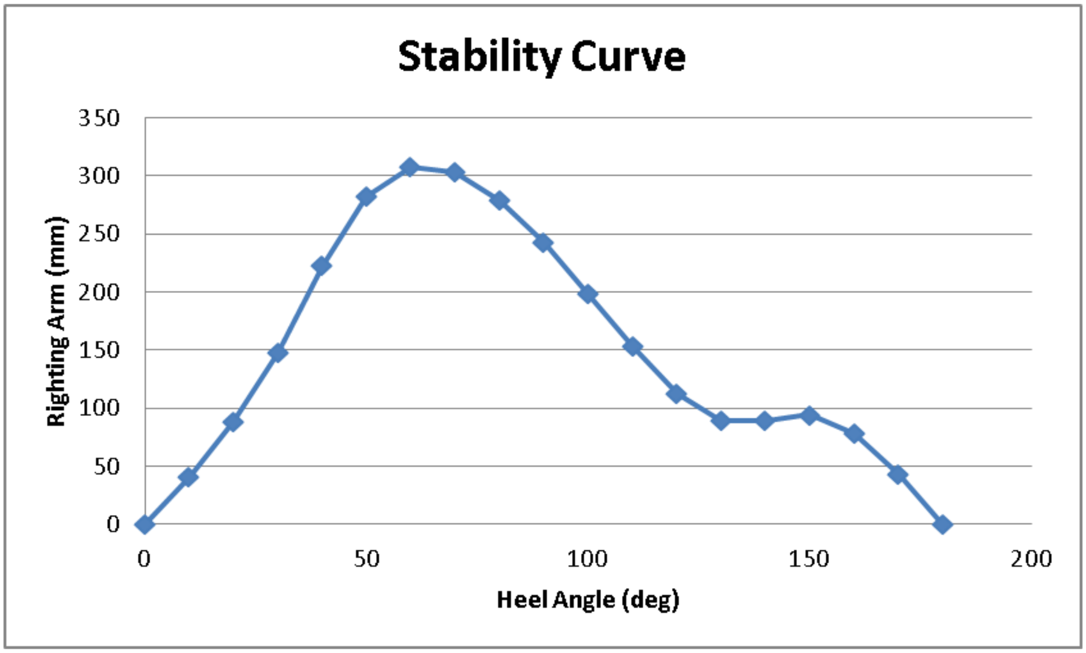

Figure 8: Stability Curve of the Baseline Vehicle

From reviewing the baseline curve it can be seen that the stability point occurs at a 60 degree tilt angle but there is another stability point at 150 degrees as well. Also noted is that the righting arm is just above 300 mm at the first stability point. When changing the center of gravity location to be half the height, or centered on the bounding box shape the curve becomes very different. The initial stability point is still at approximately 60 degrees but the righting arm at this point is only 100mm. Also the curve drops below zero and a negative stability point occurs at 120 degrees and -100mm.

Constants	
height	2082.8
width	2451.1
CG height (proe)	1041.4
RB	0.389
water height	1272.6
CG height (from Hw)	231.2
height*RB	810.2

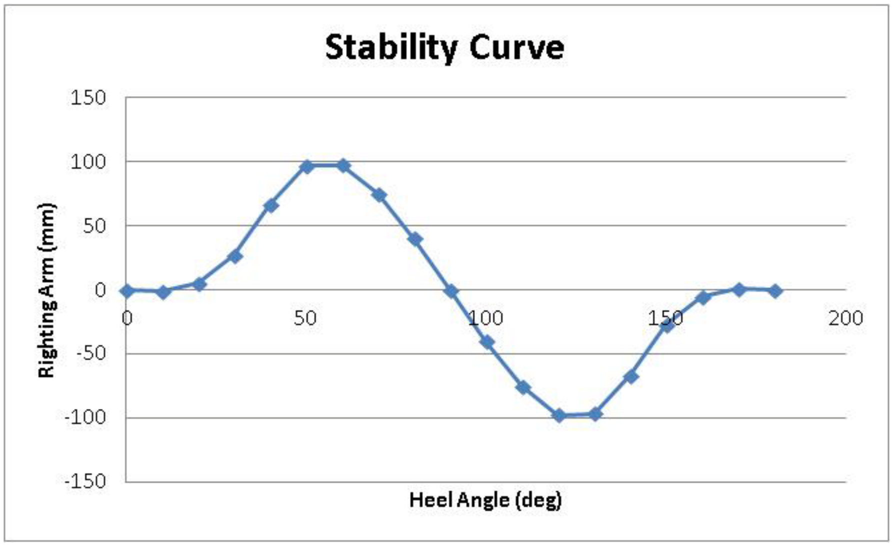

Figure 9: CG Height changed to be half the bounding box height

Again changing the center of gravity location changes the curve drastically. When the CG is above the waterline the vehicle immediately wants to tip and does not begin to right itself until approximately 110 degrees. It is also requires much more force to right itself noted by the righting arm being over -400mm.

Constants	
height	2082.8
width	2451.1
CG height (proe)	1400
RB	0.389
water height	1272.6
CG height (from Hw)	-127.4
height*RB	810.2

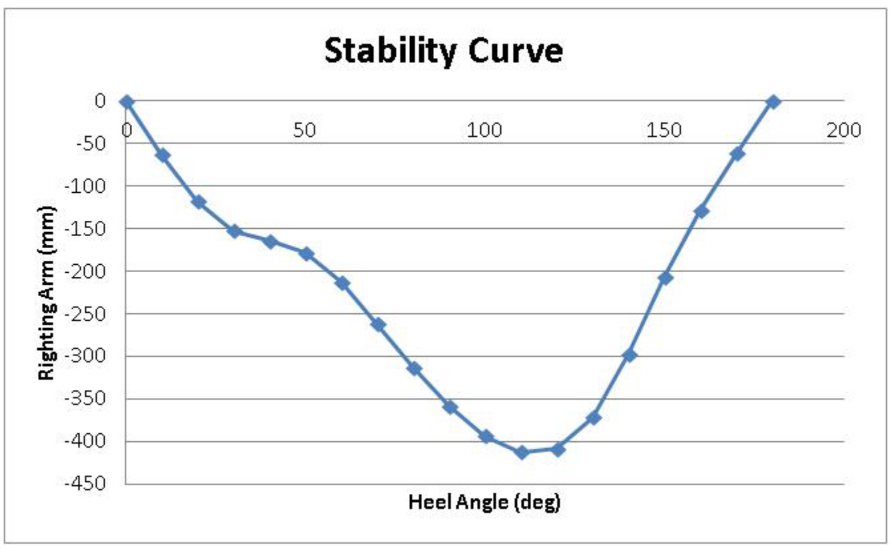

Figure 10: CG Height changed to be above the water line

With the center of gravity back to the baseline value the width and the height of the bounding box are adjusted. This does not have nearly the same effect on the curve as changing the CG did. Although the righting arm values do change the stability points are still very similar to the baseline curve.

Constants	
height	2082.8
width	2082.8
CG height (proe)	798.86
RB	0.389
water height	1272.6
CG height (from Hw)	473.7
height*RB	810.2

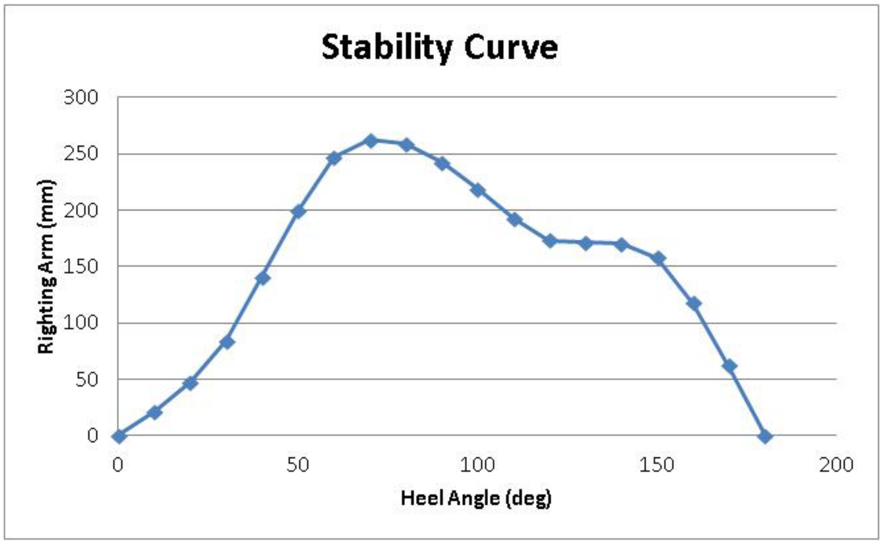

Figure 11: Height and Width are equal

Constants	
height	2451.1
width	2082.8
CG height (proe)	798.86
RB	0.389
water height	1497.6
CG height (from Hw)	698.8
height*RB	953.5

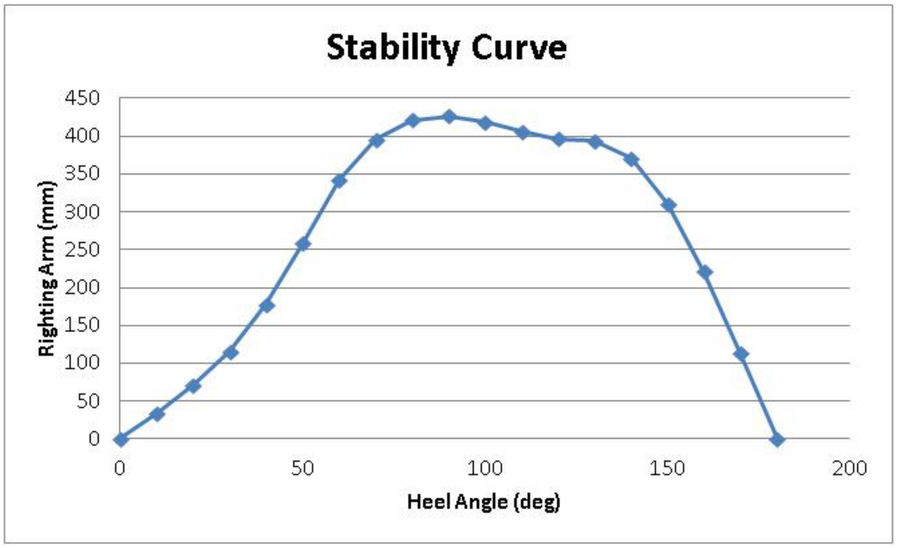

Figure 12: Height is greater than Width

The final two scenarios shown have changes to the reserve buoyancy which results in a different waterline location. Of the different scenarios tested this changes the baseline curve the least. The shape of the curve remains the same with only slight changes to the righting arm values at each stability point along the curve.

Constants	
height	2082.8
width	2451.1
CG height (proe)	798.86
RB	0.5
water height	1041.4
CG height (from Hw)	242.5
height*RB	1041.4

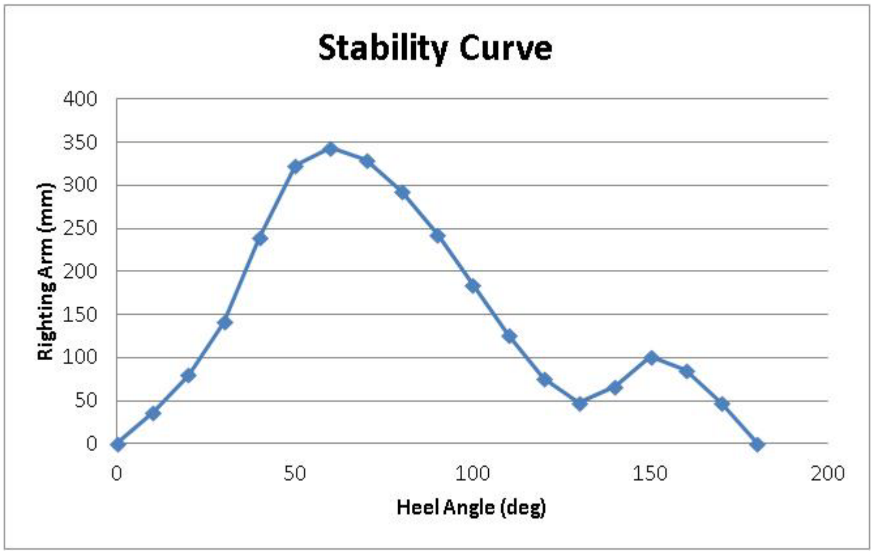

Figure 13: Reserve Buoyancy is equal to 50%

Constants	
height	2082.8
width	2451.1
CG height (proe)	798.86
RB	0.65
water height	729.0
CG height (from Hw)	-69.9
height*RB	1353.8

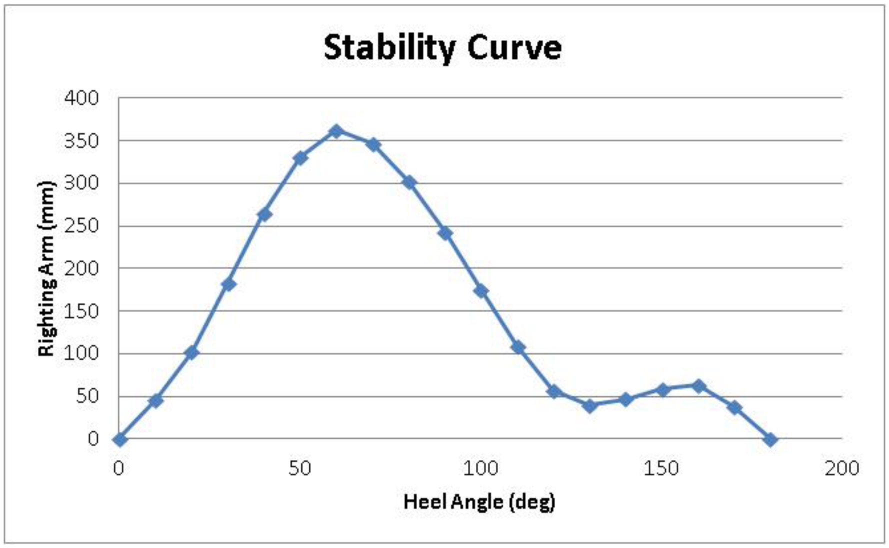

Figure 14: Reserve Buoyancy is equal to 65%

1.4 Important Findings and Conclusions

In conclusion, it is proven through this amphibious context model that there are certain parameters that effect results more than others, and if these parameters can be focused on and adjusted appropriately desired requirements can be met. For the reserve buoyancy, the density of the fluid in which the vehicle must drive through has the greatest impact, since it would be difficult to change this parameter it is best to try and adjust the density of the vehicle itself. For the range and speed, the drag coefficient has a great impact on the results and this is something easily manageable with changes in the vehicle design. Lastly the stability of the vehicle is greatly affected by the center of gravity location, therefore if it is possible to arrange the masses of the vehicle to allow for a lower CG that is best for a desirable outcome.

1.5 Implications for Further Research

Further work may be important to include more accurate bounding shapes for the stability curve results. The more closely related the bounding geometry is to the actual, the more accurate the curve will be. Therefore if more precise results are necessary incorporating a bounding polygon or other type shape will be needed. These shapes require much larger calculations and coding so they were not initially included.