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A Civil Engineering Student's Crash Course in Concrete Canoe Hull Design

Emily G. Mesker

Western Kentucky University, Emily.Kinslow775@topper.wku.edu

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A CIVIL ENGINEERING STUDENT'S CRASH COURSE IN CONCRETE CANOE
HULL DESIGN

A Capstone Experience/Thesis Project
Presented in Partial Fulfillment of the Requirements for
the Degree Bachelors of Science with
Honors College Graduate Distinction at Western Kentucky University

By

Emily G. Mesker

Western Kentucky University
2013

CE/T Committee:

Professor Matthew Dettman, P.E., Advisor

Dr. Julie Ellis, P.E.

Ms. Ami Carter

Approved by

Advisor
Department of Engineering

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2013

ABSTRACT

Every year, seniors in the WKU civil engineering department form a team and design, build, and compete with a concrete canoe. For the first time in several years, the 2013 seniors have used our own design for the canoe hull shape. I will be discussing our canoe design process: why we wanted a new shape for our hull, how we made design decisions and the actual design and analysis process, in hopes of leaving a “how to” guide for future seniors. Along with the designing process will be a discussion of the success of our final product and what we would change about our design process.

Keywords: Concrete Canoe, Hull Design, Hull Analysis, Guide

Dedicated to my family and friends
who have supported me along the way.
And to Robby Boarman, my cancer-surviving
classmate who gave me the inspiration to be
Courageous.

ACKNOWLEDGEMENTS

This project would not have been possible without the help of my advisors, family, and teammates. I am thankful to Matthew Dettman, P.E., my senior project and CE/T advisor for his critique and advice on this project, and his encouragement and support in my other projects and endeavors. After advising for 21 concrete canoes, Professor Dettman remains actively interested in the students' work, encouraging and pushing each team to do even better than the year before.

A special thanks to Dr. Julie Ellis, who has pushed me with this project, down to critiquing the way I stand while presenting. Dr. Ellis has been nothing but supportive of my involvement in the Engineering Department and is always there to give me great constructive criticism to help me learn leadership, discipline, and professionalism, skills I will take with me beyond school to help me become a successful engineer.

I would like to thank Dr. Warren Campbell, my academic advisor, for his always great advice and for going beyond the basic duty of an advisor and sharing with me information about professional conferences, scholarship opportunities, and graduate programs that he believes would be a good path for me to take. I would also like to thank the honors college for their supportive and helpful environment and for the generous financial support they have given me through an Honors Development Grant in order to complete this project.

Finally, I would like to thank my family, my friends, and my civil engineering classmates, without whom I would have never made it this far.

VITA

June 18, 1991.....	Born – Glasgow, Kentucky
2009.....	Barren County High School, Glasgow, Kentucky
2011- 2012.....	Intern, Warren County Division for Stormwater Management, Bowling Green, Kentucky
2011.....	Semester at Sea, Maymester 2011
2011.....	President, WKU American Society of Civil Engineers
2012.....	Secretary, WKU American Society of Civil Engineers

FIELDS OF STUDY

Major Field: Civil Engineering

Minor Fields: Floodplain Management and Spanish

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CHAPTER 1

INTRODUCTION

You are probably reading this because you are hoping to shed some light on your path to understanding just how you are going to design a concrete boat. This is your senior project and you know you want to make a better canoe than what you saw last year. Achieving this goal, however, is no easy feat. The concrete canoe always consists of thin layers of concrete reinforced with some kind of mesh, wire, and usually Nitonol memory wire. Every year the students strive for a lighter and stronger concrete design, innovative and affordable reinforcement, and a clean looking, fast final product. Fast. That is one of the greatest goals. Winning the races at the regional competition gives the team a much better opportunity to advance to the national competition. The races are your chance to bask in glory.

In the 2009-2011 years, the Committee on National Concrete Canoe Competitions (CNCCC) had a set hull shape that all teams had to follow. In these years, teams were on even playing fields when it came to the shape of their canoe. The innovation had to be in lighter concrete and thin hulls. Beginning in 2012, teams were allowed to change the shape of the hull within certain dimension parameters. The WKU team chose not to design a new hull in 2012, and saw at competition that hull design and innovation had to

be included to have the lightest fastest product. The canoes seen at the competitions now all have different lengths, widths, and overall shapes. Each of these hulls was designed with the intention of making the canoe faster and easier to paddle.

WKU's 2013 concrete canoe team was faced with a challenge they had never seen before. Through the years that the 2013 senior class had been at WKU, the CNCCC hull parameters had dictated what the shape of the hull would be. After seeing the 2012 regional competition and how important hull innovation was to winning, the 2013 team knew they had to create a completely new design. Even altering the previous design was not an option. The CNCCC design was stable, but slow. The 2013 team wanted a streamlined design that reduced weight and drag for a faster boat. The only problem was they had no idea where to even start. They stepped up to the challenge and through research, trial, and error developed a hull design process that worked for them. Their process is outlined and explained in the following pages to help you, the current senior class, get started on deciding what your hull design will be.

CHAPTER 2

INTRO TO HULL DESIGN

“Speed is the synthesis of every courage in action, and it is aggressive and war-like. Slowness is the analysis of every stagnant prudence, and is passive and pacifist” – FT Marinetti, *Futurist Manifesto* (Marchaj, p 4)

Though the concrete design, reinforcement scheme, and strength are all important parts of a concrete canoe project, one of the greatest foci of teams is the speed of their hull. Competition is for racing, for overcoming, and for winning. The hull design of the canoe is a key part in achieving desired speed. The hull design affects the lightness of the craft, the drag along the sides of the craft, and how easily the canoe cuts through the water in front of it.

The lightness of a boat has a great affect on how quickly it can move through the water. Let’s take a look at Newton’s laws of motion. Newton’s First Law, the law of inertia, states that an object at rest will stay at rest unless a greater, unbalanced force acts upon it. For the canoe to move forward in the water, the paddlers must first overcome the forces holding the canoe “stationary”. The greatest of these to overcome are going to be the weight of the water in front of the canoe and the weight of the craft itself. Newton’s

Second Law, related to the first, states that the acceleration of an object is equal to the force provided divided by the mass (Equation 1). The greater the mass of the canoe, the more force the paddlers are going to have to provide in order to propel themselves forward. A wider or overall larger canoe, requiring more concrete and reinforcement, will weigh more than a canoe that is shallow and narrow.

$$acceleration = \frac{Force}{mass}$$

Equation 1: Newton's Second Law of Motion

The friction and drag force on the hull of the canoe caused by pushing past the water is yet another force that the paddlers have to overcome. (Marchaj, 251) The drag force can be determined in Equation 2. You can see in the equation that as velocity increases, the drag force increases exponentially. The paddlers will still have to overcome the drag force as they paddle harder and faster, but if the frontal area (A) can be kept low, the drag force will remain lower as the speed increases. More about drag will be discussed later in the Canoe Hull Analysis section.

$$F_d = \frac{1}{2} C_d \rho V^2 A$$

Equation 2: Drag Force

Where:

C_d = drag coefficient (function of Reynold's number)

ρ = density of water

V = velocity of water running across canoe surface

A = frontal area of canoe

The shape of a canoe hull affects how the water in front of it is pushed out of the way as the canoe moves across the lake. As a canoe is a displacement hull, it has to cut through the water rather than skim on top of it. To make this easier, the hull should be as **streamlined** as possible. A streamlined body keeps the flow of the water around the hull as close to the hull as possible and not separate causing turbulence. Nature is the best place to look at streamlining: just think about how that trout you caught on the lake is shaped. (Marchaj, 240) A canoe that pushes the water around it smoothly and lets the water flow back together behind it with little turbulence will have reduced drag and move much faster.

You now have several things to consider in designing a hull that will make your canoe faster, but do not forget that straight line speed is not what wins all the races. The paddlers have to be able to turn the canoe around buoys. If the CNCCC continues to use the slalom course, the paddling team will have to turn around 7 buoys, as shown in Figure 1. (ASCE, 42) A **keel** is typically included if a team wants their canoe to track straight. No keel should be included if the team fears they will not be able to turn the canoe fast enough. The paddlers also have to be able to stay in the canoe. A narrower canoe is more streamlined and has less drag, but can the paddlers still race it without capsizing? Stability and speed, it would seem, are inversely related. One must be sacrificed for the other to improve.

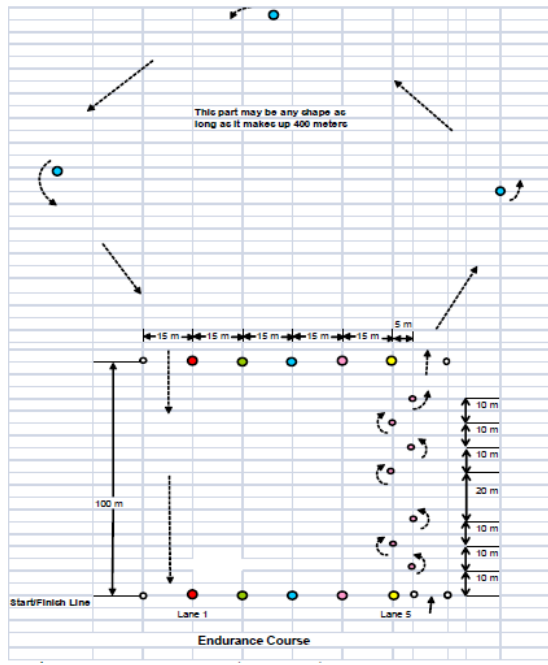


Figure 1: Example Endurance Race with Slalom
 Source: American Society of Civil Engineers 2013 Concrete Canoe Rules p. 42

CHAPTER 3

GETTING STARTED

Hull design is a critical part of the overall design of a concrete canoe. For the 2013 team, hull design came first; without a hull or form, little else could be planned or completed. As the team had no experience with this kind of design, they had to develop a plan and establish what steps they should take. The first step taken in any new design is setting goals for the project. For example, after seeing the results of the 2012 competition, the 2013 team, which I will call Team Courageous, set goals for what they wanted to see change, which was primarily weight and speed.

In the decision making and goal setting process, you should ask yourself the following questions:

1. What characteristics do we want this canoe to have?
2. What will it take for the canoe to have these characteristics?
3. What have we seen in the past that we would like to see done differently, why?
4. What have we seen in the past that works for the type of canoe we want?
5. Why does it work?
6. Lastly, is this even feasible?

Team Courageous' answers to these questions were as follows: The team wants a faster, lighter canoe. In order for this to happen, the canoe must have less material and less drag. In previous years, the designs have been wide, deep, and slower than desired. Other teams' designs that the team saw were narrower and shallower than WKU designs. These canoes were faster than WKU's. Basic knowledge of fluid mechanics leads to the conclusion that these smaller canoes had less drag forces acting on them. The goals were set to narrow the hull, make the depth of the hull shallower, and experiment with the location of the widest point to see how it affected drag. While you take a moment to ask these questions, remember that what you originally decide is not always set in concrete. Things may, and probably will, change as you move on to the initial design and analysis of your hull design.

The preliminary questions listed above will give your team the basic idea of what they want in a canoe. It is necessary, however, to have some details as to exactly what you want to see, such as dimensions and the shape of the **gunwales** and the bottom. The first place to look for inspiration is the canoes from previous years that WKU still has or that you can get records of. Look at what other teams outside WKU did with their canoes as well. Pay attention to canoes that win at the regional competition. The technical papers for the winners of the national competition are posted online for your viewing as well. You can find these at: <http://canoe.sl.c.engr.wisc.edu/designpapers/index.htm>, courtesy of the University of Wisconsin – Madison. Use what you find out about their dimensions, shapes, and successes (or lack thereof) to make decisions on the size and shape of your hull. Remember to keep the competition rules handy and make sure your decisions are

within specifications.

Research is your next step. It gives you more information about hull design of canoes and other types of displacement hulls and how they are analyzed. Start with the sources listed for this guide, and look for others. The more you understand about what you are designing, the easier it will be to make a decision that will give you the results you want. Every year that a hull is designed, a hull analysis is done. This information explains why the final hull was chosen and is a good place to start understanding the hydrodynamics behind the results the previous teams got.

Team Courageous relied heavily on books, articles, and published research in naval design and hydrodynamics to understand how the changes to the hull design they were making would affect the performance. Though not all the research was completed before hull designs were being tested in the hull design software, the analysis of the hull required research and review to understand the test values given by the hull design software. It takes understanding of the test values and the equations that back them to make an educated decision about which hull is best. Team Courageous looked mostly into stability, drag, and optimum speed, as discussed in chapter 6, because these properties were most related to the goal. Before beginning actual hull design, we found that a narrower, less curvy boat would be much more streamlined, that a shallower canoe would have to displace less water, and that having the widest **beam** at the center of a boat does not make it faster (Marchaj, 242).

After you think you have made dimension and shape decisions, make a sketch of your design labeled with dimensions. You can use this sketch as a starting point for your

hull design software (which will be discussed below), and it will go in your engineering science notebook for the project. This sketch gives you a better visualization of what your design will actually look like. Be sure to draw a plan and profile view to get the full picture. If a single decision has not been made and your team has more than one idea, sketch them all. Seeing what each design generally looks like makes it much easier to compare and narrow the choices down to a few designs.

CHAPTER 4

USING PROLINES 7 HULL DESIGN SOFTWARE

If you are thinking that you will never have enough time to find a way to render your design in AutoCAD, fear not. Team Courageous had hull design and analysis software purchased in order to speed up the design and form construction process. The team wanted a program with capabilities to create a design, export the design as an AutoCAD file, and do part of the hydrodynamic analysis. These capabilities would make decision making faster in order to have a form made soon enough in the semester. Ideas for hull design software came from looking at what the national winning teams used to design their hull. There were several different hull design programs used by the schools, but one that caught the eye of the team was Prolines V7.

The Prolines V7 hull design software, made by Vacanti Yacht Design, has all the features that Team Courageous was looking for. The basic version of the software was placed on the student use computer. This version shows the designer to see the plan, perspective, body and profile views of their hull, giving a 3D idea of the hull while being able to check for symmetry (Figure 2). The basic version also has stability analysis, hydrostatics calculations, wave and friction drag analysis, and the curves for wetted areas and wetted lengths. Team Courageous used mostly the stability analysis, hydrostatics and

drag analysis to determine which hull was best based on the goal of improving speed while maintaining an acceptable stability. Proline V7 Basic will also generate a 3D image of the hull that the user can turn and spin to look at the hull as a whole. The Pro version of the program, placed on the advisor's computer, has the ability to export the design as an AutoCAD file and other file types for use with other programs.

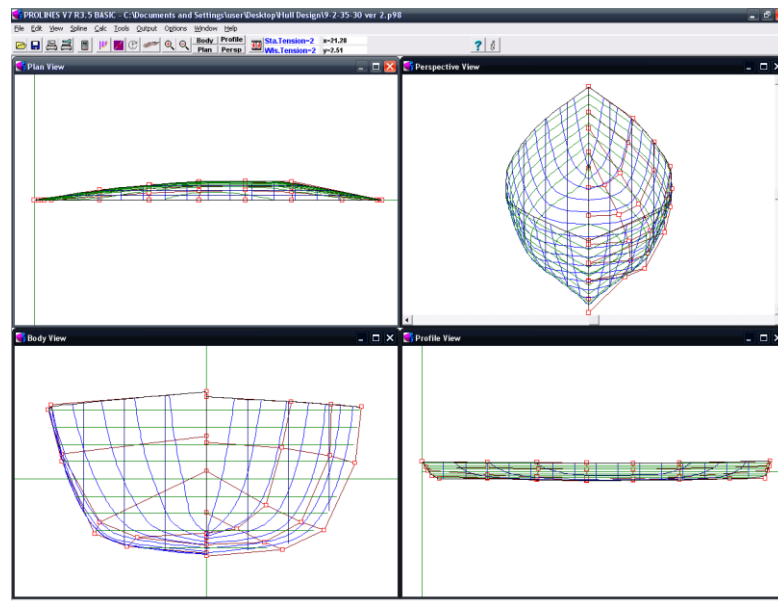


Figure 2: Views in Prolines 7
Source: Prolines V7 R3.5 Basic, Vacanti Yacht Design Software

At this point, you have Prolines 7 at your convenience and your trial dimensions decided upon. You are ready to start designing your canoe. Have a seat at the “captain’s” computer in the corner, take a deep breath, and open the Prolines 7 program you see on the desktop. Click ok when the scrolling banner pops up.

Your screen should look like this:

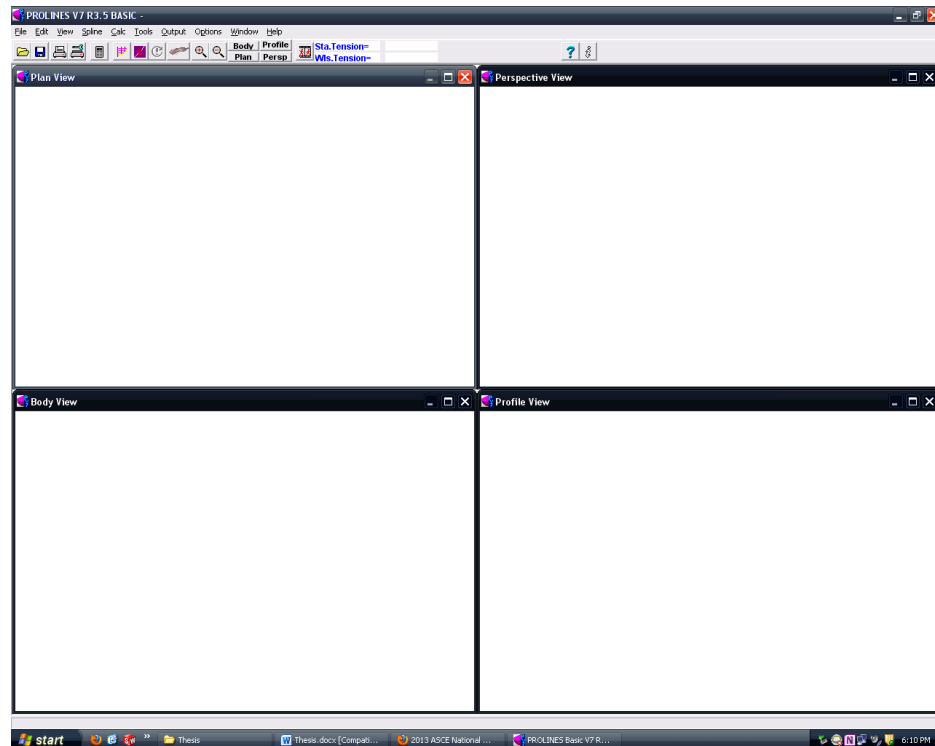


Figure 3: Initial Prolines 7 View
Source: Prolines V7 R3.5 Basic, Vacanti Yacht Design Software

Click “File” and choose “New” to create a new hull. Choose “Parametric Hull Design” and click “OK”. Now is the tricky part. What do all of those terms on the screen mean? Let’s start at the top right. The hull type is the general kind of boat you want to design. You are not planning on making a power boat or some kind of cargo ship, so choose the sailboat/round option. It may be a pain, but keep your units in inches. You will probably be describing the depth of the hull in inches, and the depth is important on this step. For **stern** type, there is a word you know! Choose a canoe type stern.

The next column on this screen is your dimensions. Put the values you decided on (in inches) in the length and ½ beam windows. Note that the value in the ½ beam is HALF of what you want the widest part of the canoe to be. Your **maximum freeboard** is the distance between the top edge of your canoe and the **waterline**. Team Courageous chose half of the maximum depth to start. The draft of your canoe is the distance from the waterline down to the deepest part of the hull. Team courageous used half the maximum depth here also. The **bow** and stern angles are what are referred to as **rocker angles**. Our team used angles of 0 here, but you may want to add some angle to it. Your screen should look similar to Figure 4 below. Click OK. Accept the default display options and click OK.

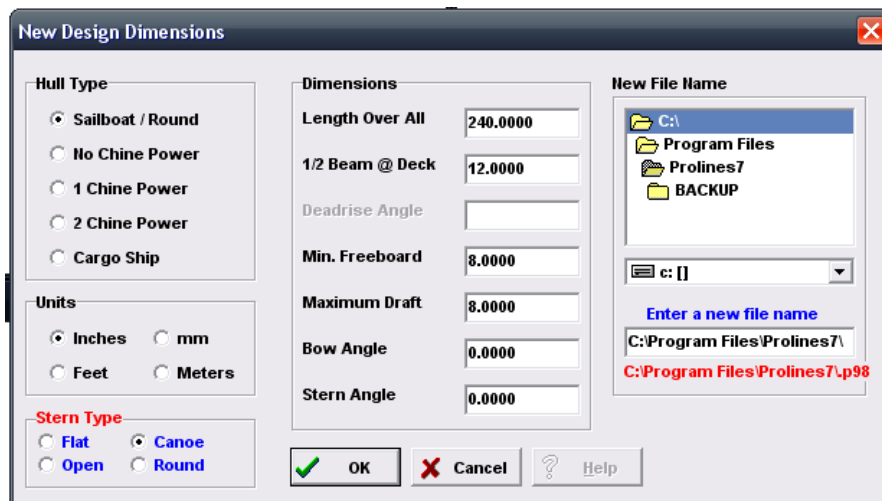


Figure 4: Initial Dimensions in ProLines 7
Source: ProLines V7 R3.5 Basic, Vacanti Yacht Design Software

Your hull shape probably looks a little less like you had wanted it to. The ends may be shaped all wrong and the wide part is not in the right place. This is not, however,

how your canoe is destined to look. It is possible to move the net of nodes that you see in order to shape the canoe.

Let's say that the figure below is what the program says your canoe looks like.

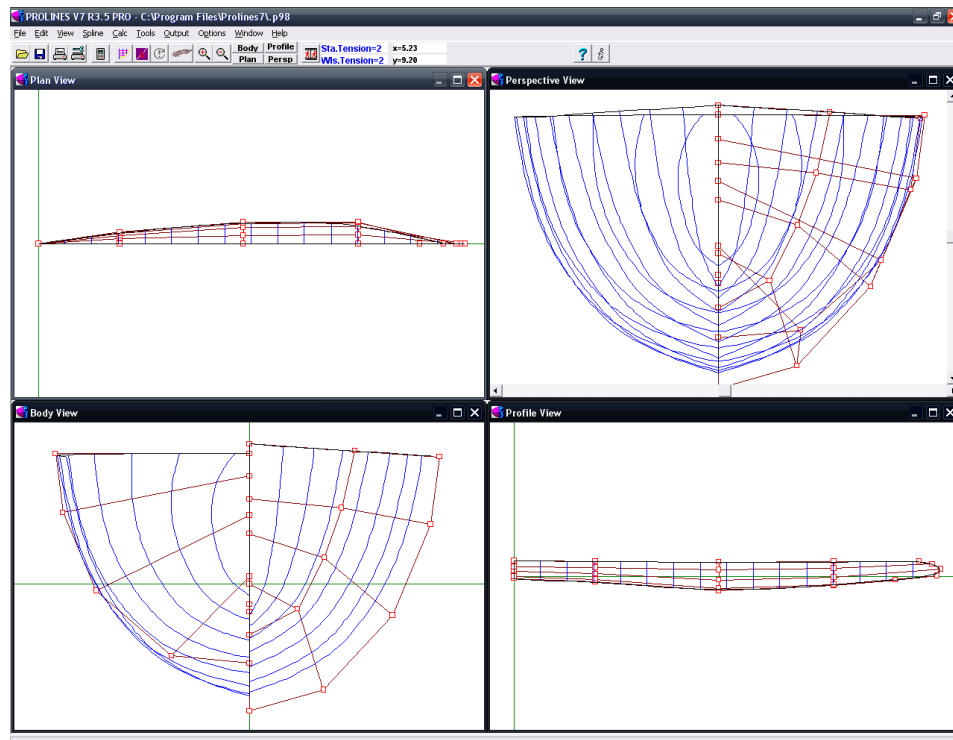


Figure 5: Sample Initial Design
Source: Prolines V7 R3.5 Basic, Vacanti Yacht Design Software

The little red squares represent nodes on columns in the “net” that makes up the shape of your canoe at the moment. These nodes can be moved to adjust the width and shape of your hull, but you first need to add more columns so that the changes you make affect the design less drastically. To do this, click “Edit” in the top left of the screen and choose “Add new vertex column”. You can choose to use the mouse to place the column, but the option of adding the column by index makes for easily spaced columns. Choose this option and indicate that you want the column after column 1 as shown in the figure.

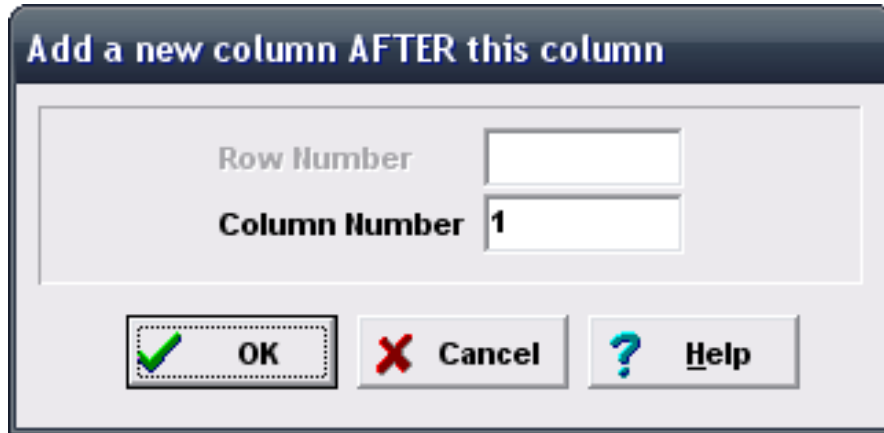


Figure 6: Adding Columns
Source: Prolines V7 R3.5 Basic, Vacanti Yacht Design Software

Notice where your new column gets placed: right in between the column on the far left and the next. The left tip of the drawing you see is Column 0. This is the front of your hull. Add several more columns where you think you will be making the most changes on the hull shape. Right now the most useful views for you are the plan view, which shows the hull cut lengthwise and looking down from the top, and the profile view showing you the side. If you accidentally add a column you didn't want to add, click Edit and Undo.

You are now ready to begin re-shaping your hull. Click "Edit" and choose "Visual vertex spreadsheet". You will see a screen like below:

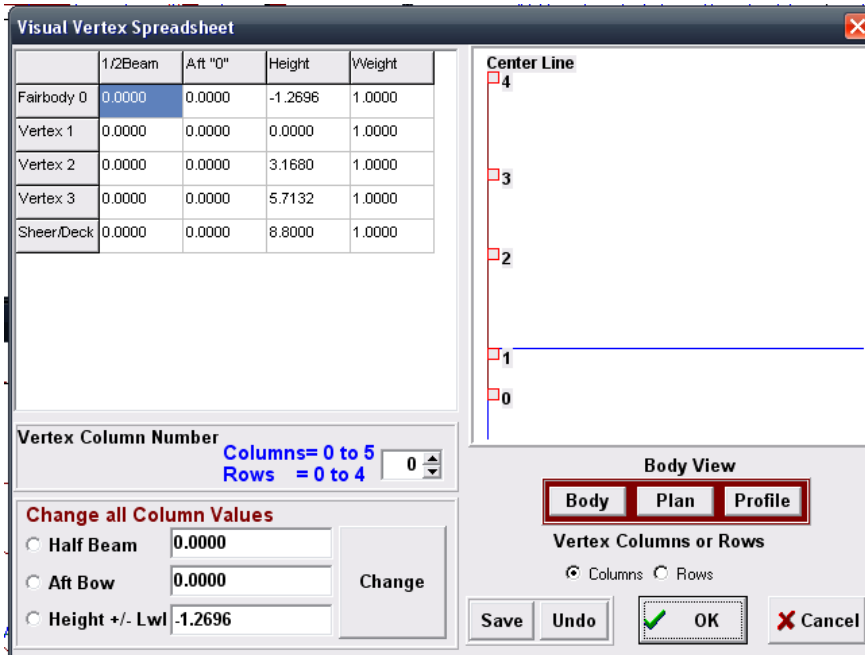


Figure 7: Visual Vertex Spreadsheet
 Source: Prolines V7 R3.5 Basic, Vacanti Yacht Design Software

Notice that you are looking at column 0. You do not want to change the side to side alignment of this column as it is the very tip of the canoe. You can, however, change the curve that it makes. In the spreadsheet, notice that all the “Aft” values are 0. These values indicate how far from the end of the boat that point is. Click “Plan” in the red box. This will show you the side of the boat so that you can see what the point is going to look like. The blue line represents the waterline. Experiment with changing the “Aft” values for each vertex and see what happens. Finish with what shape you like, leaving vertex 4 (sheer/deck) at 0.

To adjust the columns along the length of the canoe, click the “up” arrow in the Vertex Column Number box to look at the next column. Switch back to body view by clicking “Body” in the red box. Do not change the “aft” value, but rather the $\frac{1}{2}$ beam value. Based on the location of each column, assign a half width that you think would match what you want the canoe to look like at that point. To check what you have changed, click “OK” and look at the plan view. If you do not like it, return to the Visual Vertex Spreadsheet and continue adjusting. Do not be afraid to change the height of a vertex a little if needed for a smoother curve. You may also adjust the vertices by clicking on one in the picture within the Visual Vertex window and dragging it to the desired location.

Once you have adjusted all your columns running along the sides of your hull design, you must shape the back. Return to profile view and go to your last column. Team Courageous made the bow and stern of their canoe identical in curve. You may deviate from this if you like. Notice that the aft values on the last column are not 0, but refer to the distance from the front or bow of the canoe. The sheer/deck at vertex 4 should be at the maximum length you chose at the beginning. Adjust the other vertices to correspond with your desired shape. Click “OK” when you are satisfied.

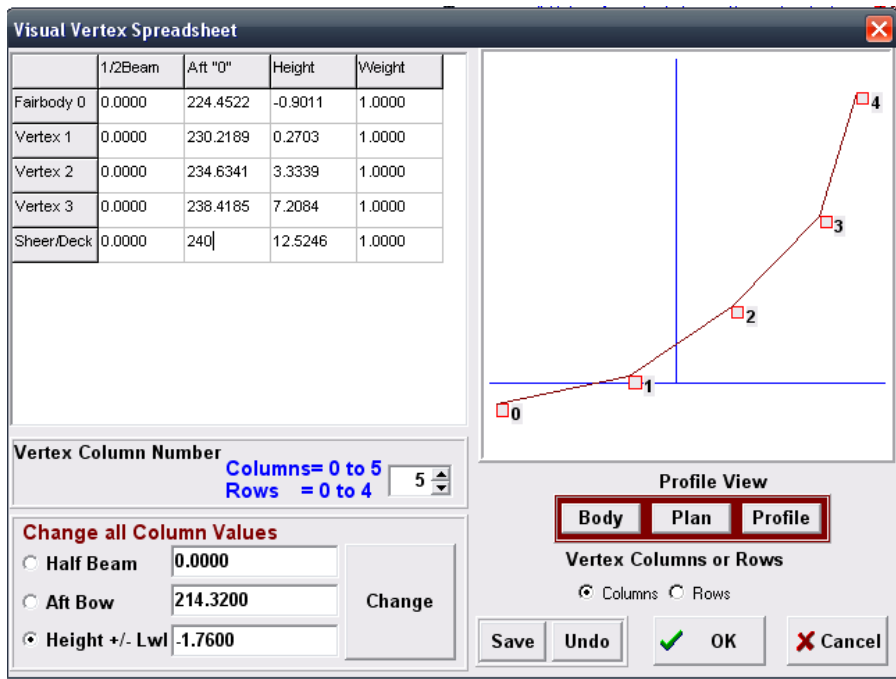


Figure 8: Adjusting the last column
Source: ProLines V7 R3.5 Basic, Vacanti Yacht Design Software

When you think you have the hull looking like you want it, you can pull up a 3D rendering of your design. This will give you a better feel on how your design will look as the actual canoe. On the tool bar, hover next to the “zoom in” button and find “Color Render Hull”. Click on this icon. A window will come up showing the 3D rendering of your hull. Use the position and angle arrows to move the hull around and take a look at your design. If you want to make changes, close the window and open and make changes in the Visual Vertex window. If you like the hull you have so far, you may want to save a picture of this rendering. To do so, click “Save as Bitmap” and save to the desired location. When you have completed your analysis and decision making, you will have to ask the advisor to export the file to an AutoCAD compatible file from his computer.

Do not forget to save your design to the computer and a flashdrive.

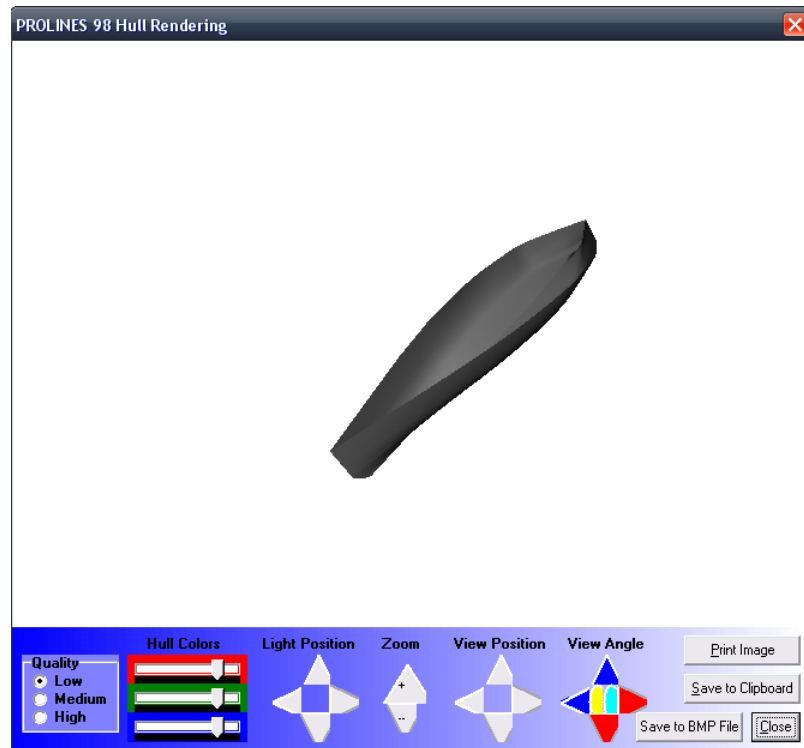


Figure 9: 3D Rendering of the Courageous hull design
Source: Prolines V7 R3.5 Basic, Vacanti Yacht Design Software

CHAPTER 5

HULL ANALYSIS

You finally have a nice looking design in Prolines 7. You have smoothed all the bumps and tweaked all the inconsistencies. You are ready to start analyzing this hull design. But first, what needs to be analyzed? Prolines 7 has all kinds of analysis capabilities and will seem to just spit out a pile of numbers if you do not know what you are looking for. What is it that you are concerned with in regards to this canoe? You may want it to be faster than last year's design, or just as fast but more stable. You may even want to look at turning. The properties that concern you most will determine what you focus your analysis on.

Team Courageous was primarily concerned with straight-line speed compared to stability. The team knew that a faster canoe would be less stable, so they wanted to make sure that the hull with the speed they wanted would not capsize too easily. Research showed that the best way to measure the stability of the hull was with the righting moment (Sponberg, 33). Speed was easily analyzed using speed to length ratio and drag. In the following sections, you will see how Team Courageous used research, Prolines 7, and a little math to analyze their hulls and determine which hull was acceptable.

Stability:

Analysis for stability is based on the righting moment. You recognize the word moment from your many classes relating to structural analysis. The righting moment, a term unique to nautical design, is the moment created by the displacement of water as the canoe **heels**. (Sponberg, 33) You know that a moment has a force (lbs) and a moment arm (length). The righting moment arm (GZ) is what we will look at and how it indicates stability. The righting moment arm is equal to the following:

$$GZ = GM \times \sin \theta$$

Equation 3: Righting Arm

Where:

GM= Metacentric Height

θ =Heeling Angle

The **metacentric height** is the height of the point where the new vertical through the center of buoyancy, as the canoe heels, crosses the original vertical through center of gravity. (CodeCogs) For a floating body to be considered stable, the metacentric height must always be above the center of gravity. (Figure 10)

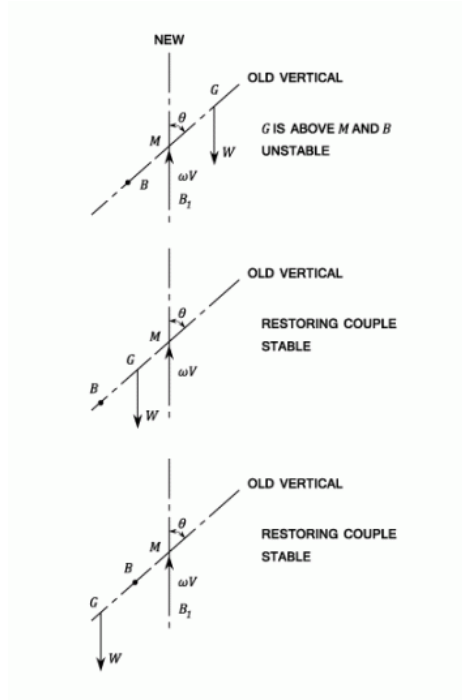


Figure 10: Metacentric Height
 Source: CodeCogs.com, Stability and Metacentric Height

When you graph the righting arm of the hull as it rolls against the heeling angle, the slope of this graph is as follows:

$$\text{Slope } GZ = \frac{GM \times \sin\theta}{\theta}$$

Equation 4: Slope of GZ Curve

When the heeling angle (θ) is very near 0, the slope of the GZ curve is GM. (Sponberg, page33) When you look at Figure 11, you see that the slope of the curve stays constant for a certain range of motion, and then begins to drop away. This slipping away indicates a drop in the metacentric height. (Sponberg, 35)When the slope of this curve reaches 0, this suggests a metacentric height of 0. If you recall from previously, the

metacentric height must remain above the center of gravity for the canoe to remain stable. A metacentric height of 0, therefore, indicates that the GM has dropped below the center of gravity and the boat is unstable.

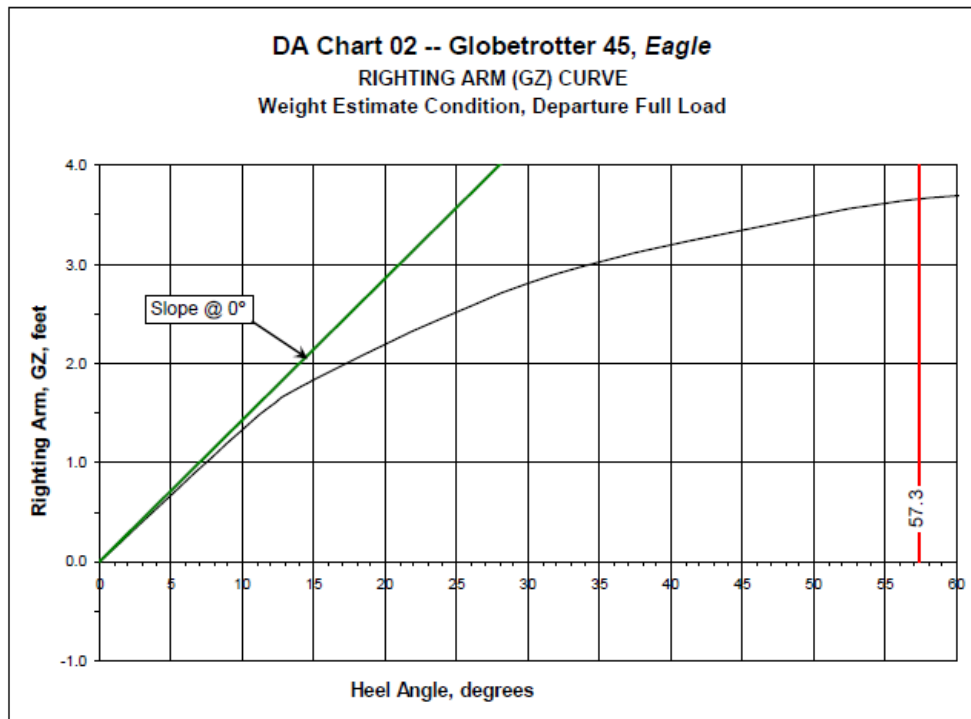


Figure 11: An example of the GZ slope and how it lowers.
Source: Sponberg, page 34

Prolines 7 can create a graph like in Figure 11 for you. Simply go to “Calc” on the toolbar and select the “Stability” analysis. When you have clicked stability, there is some information you need to put in the boxes so that you can get an accurate reading. Change the maximum heeling angle to 90 degrees because you want to see how far you can push the canoe as it heels. It may still be stable past 45 degrees. In the boxes indicating weight, fill in the weight of 2 to 4 paddlers and how far aft (back from the bow) they will be

sitting. Team Courageous used 150 lbs for each paddler and placed them at 3 feet from each end. Your screen looks something like this:

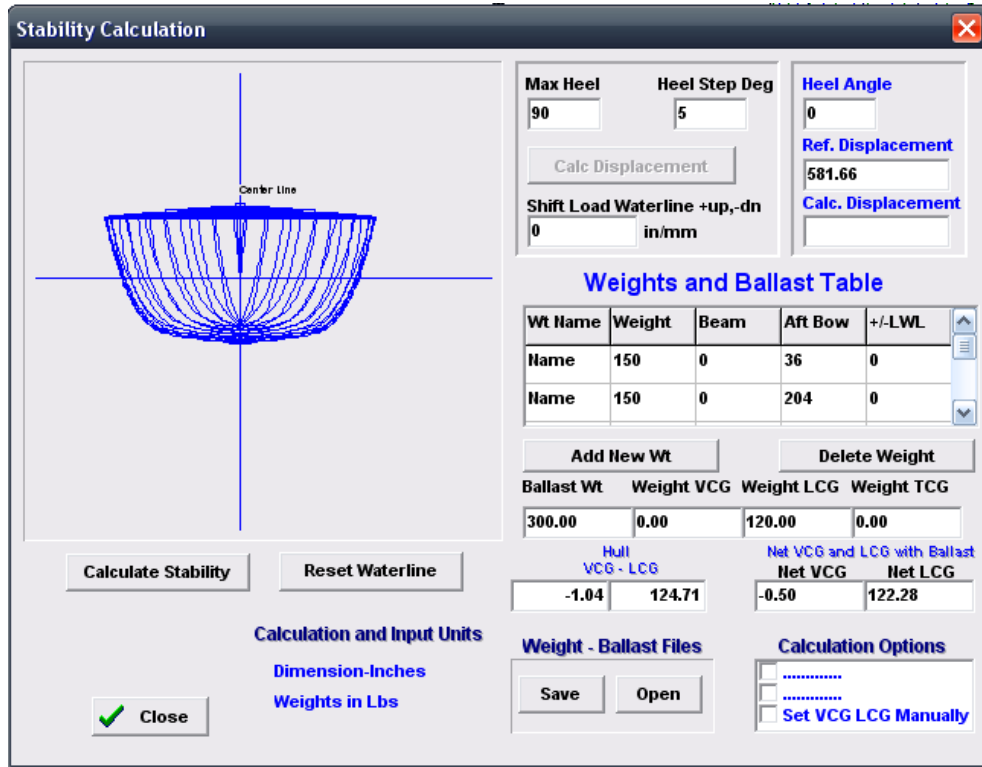


Figure 12: Setting up hull stability
 Source: Prolines V7 R3.5 Basic, Vacanti Yacht Design Software

Notice that your lengths are still in inches. Click “Calculate Stability”. The blue hull will turn as if heeling and produce a graph with a curve showing you the righting arm against the heeling angle. Courageous’ stability chart is shown below. Notice that the slope stays relatively constant until about 30 degrees and then begins to curve off. At this point, the metacentric height is dropping. The slope of the line is 0 at about 48 degrees, indicating that this is the point at which Courageous becomes unstable and will probably capsize.

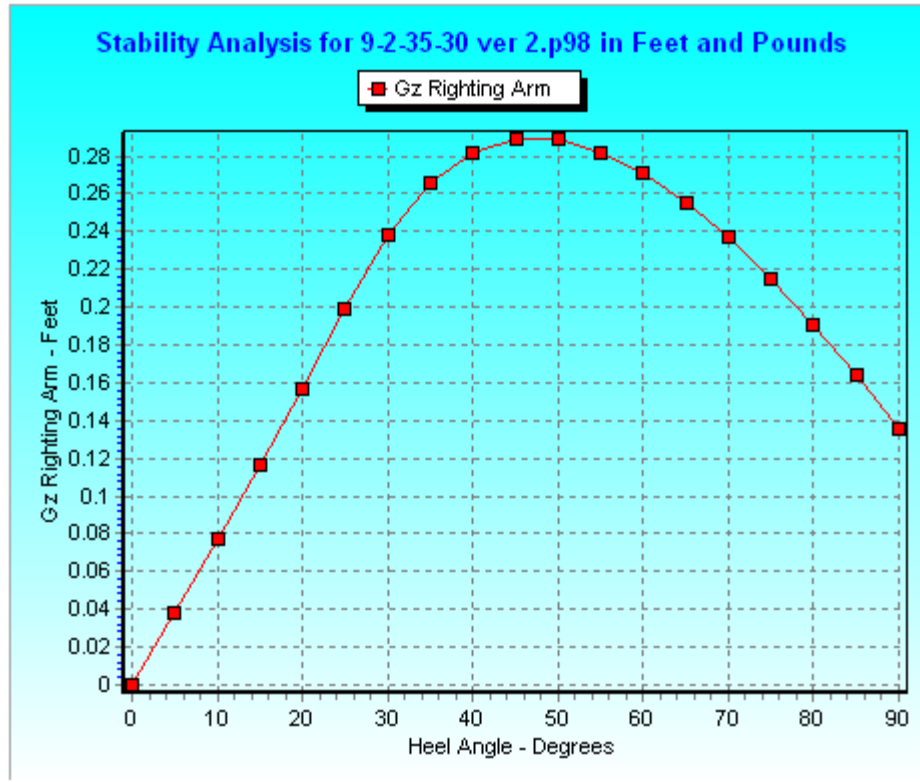


Figure 13: Courageous Stability Curve
 Source: Prolines V7 R3.5 Basic, Vacanti Yacht Design Software

Now you have to decide if this level of stability is acceptable to you. Is the angle at which your hull becomes unstable what you wanted? If it is plenty stable for what you wanted, you can move on to other analysis. If you wanted your canoe to be more stable than this, try going back to the design and making the bottom flatter or the cross section wider and run the analysis again. You may be trying several hull design ideas in order to determine which you think is best. In this case, make note of your results on this first stability analysis and go on to other parts of the analysis of the canoe. You can compare all results at the end and then go back and make changes to the design you like most.

Speed analysis:

Team Courageous used two methods to determine which hull was the fastest. The first of these was the speed to length ratio. This ratio helps you find the optimum speed, the speed at which the canoe is moving easily just before the paddlers have to paddle harder in order to overcome their own wave. The second method was looking at friction and wave drag. The lower the drag on the canoe as it speeds up, the faster it will ultimately be able to go as the paddlers have less resistance to push against.

Speed to length ratio calculations begin with some of the hydrostatic calculations provided by Prolines 7. First, however, you need to understand which calculations you need. Speed to length ratio is the ratio of the optimum speed of the hull and the square root of the length of the waterline (Sponberg, 13). For every speed to length ratio, there is a corresponding coefficient called the prismatic coefficient (Sponberg, 11). The prismatic coefficient (C_p) is used for other calculations and is the ratio of the volume of displacement of the hull divided by the volume of a prism which is the max section area multiplied by the length of the waterline (Sponberg, 10) Sponberg provides us with a table of some prismatic coefficients and their corresponding speed to length ratios (Figure 14). Using this chart and the hydrostatics provided by Prolines 7, you can calculate your optimum speed.

Speed/Length ratio	Cp
1.0	0.52
1.1	0.54
1.2	0.58
1.3	0.62
1.4	0.64
1.5	0.66
1.6	0.68
1.7	0.69
1.8	0.69
1.9	0.70
2.0	0.70

Figure 14: Speed /Length Ratios and Prismatic Coefficients
Source: Sponberg, page 11

To find the hydrostatic calculations in Prolines 7, click on “Calc” and choose the “Hydrostatics” option. The window that you see should be similar to the picture below. Notice that you are provided with many coefficients, some used for calculations that we will not use here, along with the dimensions of your hull, including the load or length of the waterline (Lwl).

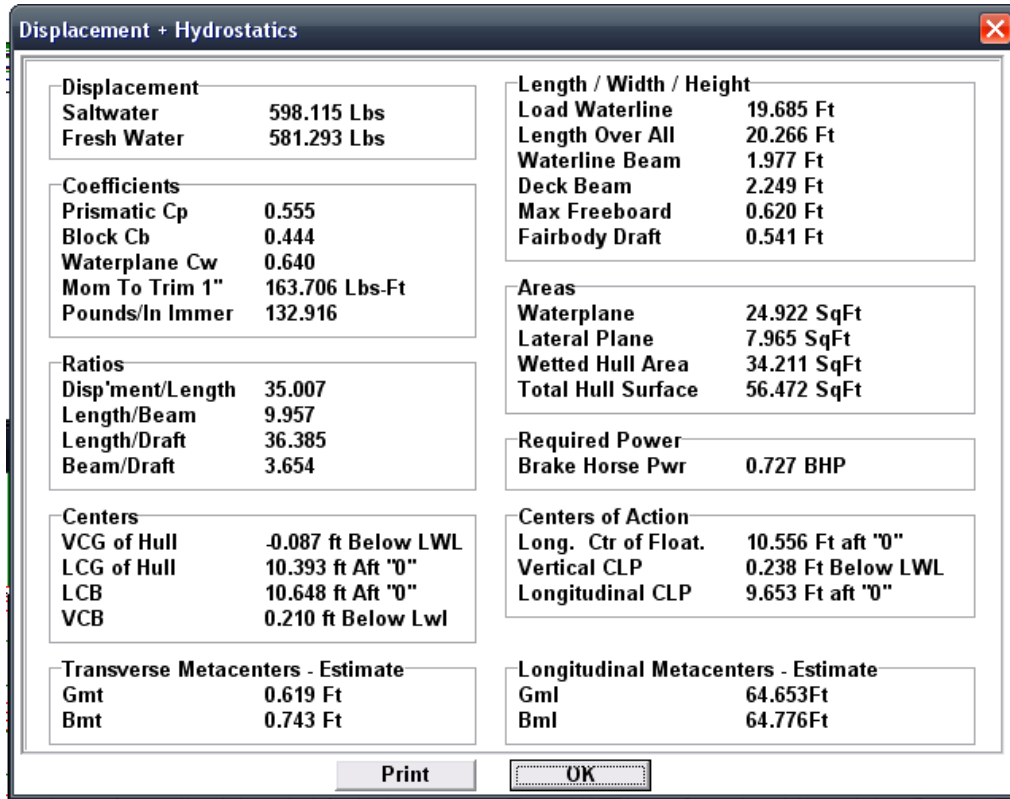


Figure 15: Hydrostatic Calculations in Prolines 7
 Source: Prolines V7 R3.5 Basic, Vacanti Yacht Design Software

You now have the Cp and Lwl to complete your calculations for the optimum speed of the canoe. Use the Cp and the chart in Figure 14 to iterate an appropriate speed to length ratio. For Courageous' results shown in Figure 15, the speed to length ratio chosen was 1.15. The equation for finding optimum speed is as follows:

$$\frac{\text{Speed}}{\text{Length}} = \frac{V}{\sqrt{L_{wl}}}$$

Equation 5: Optimum Speed

V is the optimum speed you are trying to find. You have the speed to length ratio and the Lwl in feet. Place these values in the equation and solve for your optimum speed. For Courageous, this value was 5.1 knots. This is about 8.6 feet per second.

You also need to look at the drag on the canoe and it's possible effects on your speed. Your paddlers will get tired. The races seem short until you are actually in the middle of one. If the drag on the canoe is high, it will be much harder for the paddlers to overcome and they will not be able to paddle as fast by the end of their race. As noted earlier, overall drag is as follows:

$$F_d = \frac{1}{2} C_d \rho V^2 A$$

Equation 2: Drag Force

There is little that can be done about speed in the equation, but you can reduce the “frontal area” (A) of your canoe. Look at the body view of the canoe in Prolines. The widest beam times the largest draft is your frontal area, the largest area the water has to move past. An overall narrower canoe will provide for less drag. How do you decide, though, which of your canoes has the lowest drag? Due to time constraints, Team Courageous did not do any extensive calculations on this, but rather observed the chart that Prolines 7 generates. This chart graphs the friction and wave drags separately against velocity (in knots) of the canoe. The graph for Courageous showed the following:

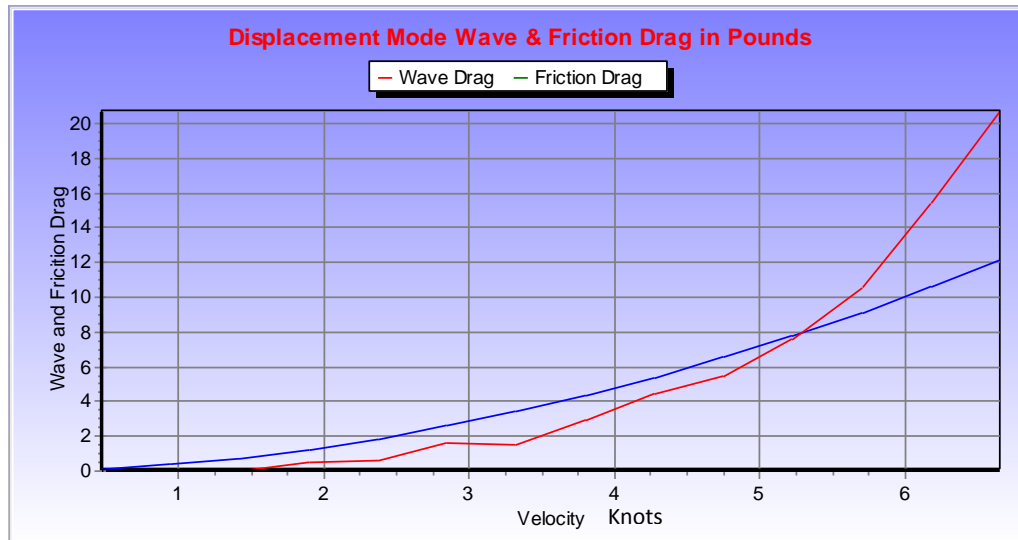


Figure 16: Wave and Friction Drag for Courageous
 Source: Prolines V7 R3.5 Basic, Vacanti Yacht Design Software

Notice how drag overall rises as the canoe moves faster. This is to be expected. The drag, however, did not seem to increase quickly until after 5 knots. Friction drag was the controlling factor up to approximately 5.2 knots, where wave drag greatly increases. It seems there is some relationship between this phenomenon and the optimum speed of the hull (5.1 knots), but I have not researched this relationship in depth.

The analysis methods up to this point are what Team Courageous used based on their goals for the new hull design. You may want to do further research and look into other methods of analysis based on the goals you have set this year for the team. There is a world's worth of knowledge on naval architecture and boat design to help you out.

Though this guide may not provide all the steps you want to take, it should serve as a guide and starting point to make designing something you have never seen in your classes before.

CHAPTER 6

REFLECTIONS

On the 2013 concrete canoe team, Team Courageous, I was the assistant captain for the project. One of my main responsibilities was to oversee the design and analysis of the new canoe hull. When the captain and I sat down to start this design, we had no idea where to even start and two weeks to get it figured out. How to build a boat is not covered in any curriculum in the major and since before we were freshman the team had used a pre-determined shape that needed no analysis. We had to develop our own process, which has been explained in this guide and left for the future senior classes who pursue the concrete canoe.

The steps I have outlined are now a smooth process. This was most definitely not the case while we were in the middle of it all. It took trial, error, searching through a handbook that was only slightly helpful, and some initial guesswork. For it being the first time in years that the team design our own hull, the process was surprisingly successful. Though hull design is not covered in civil engineering curriculum, we are trained problem solvers. We know the basics, we are observant, and we figure out what backs up our gut decision. That is how the Courageous hull was designed.

I have shared with you that Team Courageous' design was intended to improve speed in our races. Based on observations from the 2012 competition, the canoe is much faster. We had the same two men competing in the men's sprint both in 2012 and 2013 years. There was a significant difference in time and placement from 2012 to 2013. The men improved upon their time by several seconds and placed first rather than third. The women, who were mostly inexperienced with actually racing, did not place better in 2013, but reported a great difference in how easy it was to paddle the new hull compared to the old hull design they practiced in while learning to paddle.

One of the unexpected negative results of the new hull design was in turning. Previous designs had the momentum to keep turning after the paddlers quite braking in a turn. In Courageous, paddlers had to back paddle, or brake, for nearly the full 180 degrees of a turn around a buoy. The shallower shape of the canoe was great for two paddlers, but when there were four paddlers in the canoe during the co-ed sprint, the waterline was too high and the canoe took on some water in the canoe. Taking on water was also due to instability. The bottom of the canoe was quite rounded and tilted easily. With four people leaning on the sides rather than two, the edge of the canoe tipped farther.

I would consider Courageous a successful design. It accomplished the goals we wanted it to: it was fast and did it was not too unstable for the 2 person paddling teams. The unforeseen negative effects of the hull design are something to be improved upon next year. From experience and observations of the performance of Courageous, I think we should have made the bottom of the hull flatter in shape and considered turning in our analysis and observations the first time. I am happy with the outcome of our canoe, but it

is my hope that the process Team Courageous went through and the mistakes we made serve as a guide and a starting point for future teams to build an even better canoe and go to nationals with a product they can be proud of.

GLOSSARY

- Beam: width of a boat at any point
- Bow: the front end of a boat
- Gunwales (gun-nals): the sides of a boat
- Heeling: turning or rotating of a boat from side to side along its longitudinal axis
- Keel: raised, pointed “line” along the bottom of a boat to help it track, or stay on path; Visually, a keel makes the curve along the bottom of the canoe seem to come to a slight point in the center.
- Maximum Freeboard: the distance between the top edge of a boat to the water
- Metacentric height: height of the point where the new vertical through the center of buoyancy, as the canoe heels, crosses the original vertical through center of gravity
- Rocker angles: angle of measure between the tangent of the lowest point on a boat to the point where the “bottom” of the boat stops and curves up into the end
- Stern: the back end of a boat
- Streamlined: shaped so that the fluid will flow smoothly around the surface of the object and the flow does not separate from the object.
- Waterline: “line” the water makes around the outside of a boat, often used as a point of measure.

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