

Integrating Technology and Engineering With a Marine Design Contest and 3-D Modeling

By John Hammons

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Boat Design Competition

The Northrop Grumman (now Huntington Ingalls Industries, Incorporated) Apprentice School, in cooperation with several area businesses, sponsors an annual boat-design competition for high school students to increase awareness of the naval architecture profession and the shipbuilding industry.

The competition engages students' math, science, technology, and creative abilities and introduces them to engineering concepts, drafting, project planning, and leadership principles. The parameters of the competition challenge students to design a fast and maneuverable boat that will carry three different payloads such as golf balls, sandbags, and crates. The hull must be made from two sheets of 1/8” steel plate measuring 5 by 10 feet. The last constraint is that a 6-inch freeboard, which is the distance between the waterline and deck edge of a boat, must be maintained. During the first stage of the competition, students have to complete and submit a design package consisting of the following items:

- Design history notebook
- Completed calculations spreadsheet
- Design drawings such as manufacturing drawings and loading diagrams
- A nesting plan

In the second stage, all of the design packages are independently judged, the top four designs are selected, and their boats are actually built by Newport News Shipbuilding apprentices. Each of the four top teams compete in “sea trials” on Lake Maury at the Mariner’s Museum in Newport News, VA to determine the winning design entry. Sea trials are comprehensive performance tests that are conducted by the shipyards at sea after the completion of a ship’s construction and before releasing the vessel to a client or Department of the Navy. A significant highlight of the competitive event is that it provides a “real-world” engineering design activity that is free and open to all area high schools. Since the competition is underwritten by the Northrop Grumman Apprentice School and several area businesses, there are no costs or entry fees to school divisions, teachers, or competing teams.

During the 2010 Society of Naval Architects and Marine Engineers (SNAME) Boat Design competition there were fifty teams consisting of 287 students from across the Commonwealth of Virginia and two teams that entered the competition from other states. Of the 50 teams that entered the competitive event, only 23 submitted completed design packages and were considered for the construction stage of

the competition. While half of the entries did not make it to the full competition, this did not mean that their effort went unrewarded but rather reflects that intense competition and rigorous application of math, science, and engineering skills are required by each of the teams to design a boat. It also demonstrated that some teams had difficulty in finishing their designs. Northrop Grumman, the contest sponsor, took the opportunity to carefully review the top competitors' design packages to identify knowledge, skills, and strategies common to the top teams to share with future teams to raise the competitive bar and broaden the field of successful contestants.

As a technology and engineering design teacher at York High School in Yorktown, VA, I introduced my classes to the SNAME Student Boat Building contest. Accordingly, the students were enthusiastic about the idea of participating in the contest and applying skills they were learning in our 3-D modeling and engineering design classes. As our team's sponsor, I assisted and guided each of the teams competing at the highest level of the 2010 boat competition. Of the 23 designs that were considered for the construction stage, four came from York High School, and all of these four ranked in the top eight. And out of these four, two were named finalists, and one won the championship trophy on April 17th, 2010.



Figure 1. Shown here is the *Crimson Tide* boat as designed by one of the York High School teams for the 2011 competition. The boat was constructed by apprentices at Northrop Grumman in Newport News, VA. The *Crimson Tide* finished in third place in the 2011 competition.

This year was the fourth that York High School had teams participating in the Boat Design contest. We had a winning team in the 2009 contest, and the previous year, 2008, our team finished runner-up in its respective competitions. In addition, York High had a team finish in third place in the 2011 competition with its boat named *Crimson Tide*, Figure 1.

While York High School has had successful teams competing in the Boat Design contest over the last few years, it is significant to note that this competitive event has provided our students with the opportunity to apply science, technology, engineering, and mathematics skills on real-world projects in our engineering drawing and design classes at York High School. Much the same as engineers and designers at Northrop Grumman design aircraft carriers and submarines, our students use similar skills as they explore and use engineering and 3-D modeling techniques. It is not my intention to write an article highlighting my successes, however. I am simply trying to help close the gap, mentioned above, by showing other teachers that there is a simpler way to complete your designs and also to promote a great engineering activity for high school students.

Challenges and 3-D Modeling

There have been four main challenges our teams have had to overcome during the past four years. They are: time constraints, the ability of students to apply the math skills necessary for the competition, the integration of a 3-D modeling software application, and the acquisition of enough ship- and boat-design knowledge to assist my students with their math, science, and technology problems. What follows describes how our teams at York High School addressed these challenges.

Time

This competition can become difficult and time-consuming depending on the complexity of the students' designs. A substantial amount of time is required to meet the competition guidelines; thus, we have integrated the activity into our curriculum so we can devote my class time to it. Why reinvent the wheel? We integrate this activity into our instructional schedule much the same as many technology teachers may do with Technology Student Association (TSA) activities. Typically we begin this activity during the first six weeks of the second quarter in class, as it meets Virginia's Career and Technical Education (CTE) competencies in both "Introduction to Engineering" (<http://www.cteresource.org/verso2/>

framework/tasklist/technology_education/engineering_drawing_and_design/2010/8436) and “Engineering Drawing & Design” (http://www.cteresource.org/verso2/framework/tasklist/technology_education/introduction_to_engineering/2010/8490) classes. In both of these classes, we work the equivalent of one hour a day, five days a week, for six weeks. It is important to note that it takes a commitment by the students and the technology teacher to complete the designs and meet all of the contest requirements by the established deadline. Perhaps this may explain why there are some teams that do not get the designs completed and submitted by the deadline. I would imagine that it would be a difficult challenge to do this activity after school as a club activity. Based on my experience, I would recommend that such a contest be integrated into the teacher’s instructional plan so that it meets a variety of state and national standards such as ITEEA’s *Standards for Technological Literacy: Content for the Study of Technology (STL)*. STL Standards 9 and 11, shown below, are readily met with the learning activities experiences in these two classes.

Standard 9 – Students will develop an understanding of engineering (ITEA/ITEEA p. 99).

In order to comprehend engineering design, students in Grades 9–12 should learn that:

- I. Established design principles are used to evaluate existing designs, to collect data, and to guide the design.
- J. Engineering design is influenced by personal characteristics, such as creativity, resourcefulness, and ability to visualize and think abstractly.
- K. A prototype is a working model used to test a design concept by making actual observations and necessary adjustments.
- L. The process of engineering design takes into account a number of factors.

Standard 11 – Students will develop the abilities to apply the design process (ITEA/ITEEA, p. 115).

As part of learning how to apply design processes, students in Grades 9–12 should be able to:

- M. Identify the design problem to solve and decide whether or not to address it.
- N. Identify criteria and constraints and determine how these will affect the design process.
- O. Refine a design by using prototypes and modeling to ensure quality, efficiency, and productivity of the final product.
- P. Evaluate the design solution using conceptual, physical, and mathematical models at various intervals

of the design process in order to check for proper design and to note areas where improvements are needed.

- R. Evaluate final solutions and communicate observations, processes, and results of the entire design process, using verbal, graphic, quantitative, virtual, and written means, in addition to three-dimensional models.

Math

The boat design teams can very quickly find themselves faced with solving complex mathematics problems as part of their design requirements. For example, one of the first calculations that the students must make, using the spreadsheet data provided by SNAME, is to determine the weight of their boat. To determine the weight, the students must calculate the area of each of the plates that make up their boat hull design and multiply it by the density of the steel, which is 5.1 lbs/sq. ft. If a plate is triangular, square, or rectangular, then this calculation is nothing more than skills typically learned in middle school math classes. However, most of the ship designs go beyond simple geometric shapes. For example, if designs encompass curved planes or edges, students will need to use integral calculus problem-solving skills to determine the area of irregularly shaped plates. Generally, there are just a few high school students capable of solving these higher-level math problems.

The area of the plates of the barge shape in Figure 2 may be calculated fairly easily by high school students. This drawing comes from the competition guidelines that are provided by SNAME and is associated with their example of how to calculate area and weight of a boat. However, students will not want to design a boat hull as plain as a barge. They will

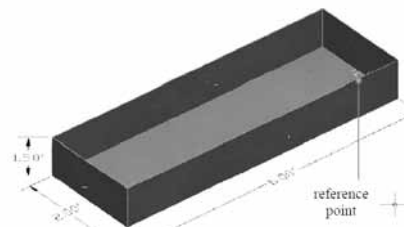


Figure 2. The boat design teams are provided with a simple hull design that provides them with insights into concepts related to calculating the area and weight of the hull plates.

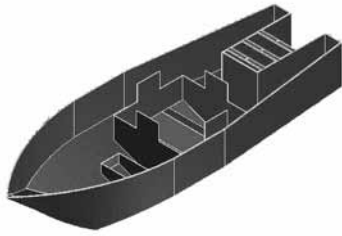


Figure 3. Typically students will sketch and design hulls that are based on curved surfaces. The curved surfaces require more complex mathematical skills to calculate the hull plate surface area and weight. This can cause student frustration in attempting to analyze the hull.

want to be more creative and design a hull such as in Figure 3. Looking closely at Figures 3-5, you will notice some curved edges and planes on these boat designs. This is typical of student work produced during the competition.

Calculating the area of these curved plates can be a challenge for many high school students and thus make their weight calculations difficult and frustrating. It can also lead to their team's inability to complete a design package. The math problems do not end with calculating plate area and weight. After weight calculations are made, the students are challenged to calculate the centers of gravity (transversal, longitudinal, and vertical) of each plate. Again, finding the centers

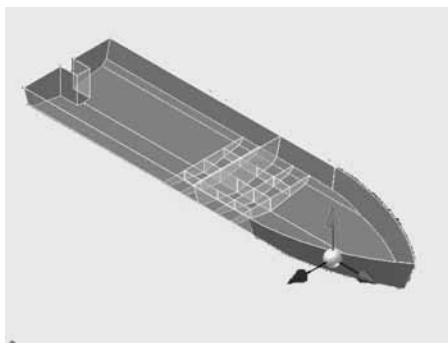


Figure 4. The "Derived Component" feature of Inventor can be used to produce a "Phantom" boat or a boat without physical properties (shown here by middle part of the structure). The "Thicken" tool is used to give a plate some physical properties, shown by the shaded area. A work surface is shown with one curved plate "thickened" and its associated center of gravity.

of gravity of a triangular, square, or rectangular plate should not be that difficult for a high school student. But finding the center of gravity of a curved surface will also require higher-level math. Figure 4 shows a mono hull design shown in "work surface" form and its associated center of gravity.

Finally, students are challenged to perform hydrostatic calculations (displacement and centers at the design waterline) by using Simpson's Rule. Use of Simpson's Rule requires determination of half-breadth distances (or distance from centerline to the hull of the boat) and the area of complex shapes if this calculation is to be performed manually, Figure 5. Simpson's Rule is also higher-level math most high school students would find difficult.

Integration of 3-D Modeling Software

It is important to recognize that mathematics plays a significant role in engineering and design fields. In the context of the boat-building competition, I found that the mathematical skills needed to solve some of the equations and problems required a much more advanced level than my students were prepared for. Most of the students in my Engineering Drawing and Introduction to Engineering classes were enrolled in Algebra, Geometry, or Algebra II/Trigonometry classes and were not prepared to solve calculus problems. It was beyond the scope and time constraints for me to include sufficient instruction in Calculus to make the necessary calculations for the hull designs. Accordingly, there were several options available to our classes and teams to generate the necessary data for our designs and meet the data and calculation requirements of the contest. However, where practical, students applied their math skills to solve problems, thus highlighting the importance of mathematics to engineering design.

$$\text{Simpson's Rule} = \frac{h}{3} (A_0 + 4(A_1) + 2(A_2) + \dots + 4(A_{n-1}) + A_n)$$

Where:

n = number of intervals (must be an even number of equally spaced intervals, resulting in an odd number of sections)

h = interval length (either section spacing or waterline increments)

A = area below design waterline (section or waterplane)

Figure 5. Simpson's Rule

Recognizing that 3-D modeling applications could be used to perform analyses that were necessary for the competition, our teams used several features of Version 11 of Autodesk's Inventor™ along with a contest-provided spreadsheet template to generate the required mathematical design data. A major part of the students' responsibility was to create a good 3-D model design and use the features of Inventor™ to generate the data. Using this approach enabled me to make the connections between math and science skills, engineering design, and using technology to solve engineering design problems. This enabled me to assist my students to compete at the highest levels in the boat design contest! While this approach met our needs in working with sophomore and junior level students who had not taken calculus, you may find that your students have the necessary math skills to perform all of the calculations manually. This of course, is an instructional decision that the technology teacher must make.

As you probably already know, there are a number of 3-D modeling programs available that are used by engineers and schools. However, my school division has purchased Autodesk Inventor, and thus that is what we use in my Engineering Design and Introduction to Engineering classes as well as the boat-design competition. While there may be other 3-D modeling applications that can perform similar functions, we will focus on how we used Inventor for our teams. Again, it is important to note that my classes consisted of mostly sophomores and juniors who had not yet taken precalculus or calculus. Additionally, the SNAME competition is designed to generate interest in the marine engineering career field. If the competition becomes too difficult, it may scare students away and not generate any interest in an engineering or technical field. Should a student wish to pursue an engineering career, he/she will have been exposed to the engineering design process and the need for advanced mathematical skills.

There are some prerequisites for Inventor R11 that students had to know before I engaged them in the competition. They had to know some basics of using Inventor, such as how to sketch and apply dimensions and constraints in order to create a part. They also had to know how to create multiview and isometric drawings. Before we began the competition, I taught my students Chapters 1 through 6 and Chapter 8 of *Parametric Modeling with Autodesk Inventor R11* by Randy Shih and published by Schroff Publications. The balance of the 3-D modeling program skills and knowledge that were necessary for the competition were demonstrated as needed while they were participating in the design stage of the competition.

There were four major concepts of the 3-D Modeling Program necessary for students to master. The first one was simply using the “area” tool in Inventor to obtain the area of all the surfaces of their models. The area tool, Figure 6, displayed the area of all plates, including those with curved surfaces. You can probably imagine how much easier it is for a student to make a few mouse clicks rather than perform several calculus equations! The second concept was to utilize the “Derived Component” feature and “Center of Gravity” tool in conjunction with each other to find all the centers of gravities (transversal, longitudinal, and vertical) of the boat plates. Third, I taught my students how to use the combination of work surfaces, work points, and 3-D sketches in order to calculate the necessary half-breadth distances. Lastly, we used the sheet metal features of the 3-D modeling program to create our nesting plans. The “flat-pattern” feature is especially helpful to flatten any hull plate that has curved surfaces.

Calculations Spreadsheet

It is important describe some of the “calculations” spreadsheet because it is an integral part of the design phase. Additionally, it is one of the three “deliverables” teams must provide by the initial deadline. The purpose of the calculations is to analytically predict how the vessel will float, which is an important step in the design of a boat—for teams have typically had to redesign their boats in order to have them either trim as desired or meet the 6-inch required freeboard.

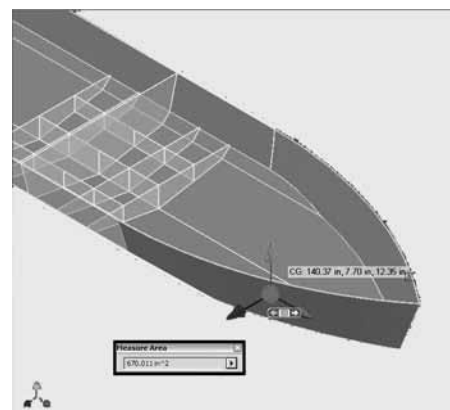


Figure 6. The “Measure Area” tool can be used to calculate the area of a boat hull plate, including curved surfaces, quickly and easily. The Center of Gravity feature of Inventor can be used to obtain values for all three centers of gravity—transversal, vertical, and longitudinal—for a boat hull plate. These values can then be entered into the spreadsheet by the students.

These calculations emphasize the necessity of the need for math skills in the design process. In other words, it is the instrument used by students to create mathematical models of their boat designs. Technology teachers will find that the most intensive integration of STEM concepts will occur when students are using their spreadsheets to analyze data. The reason I believe it is so intense is simply because it has no graphical display of the boat designs and therefore will require your students to learn nautical concepts and terminology. Most, if not all, designer software packages on the market have graphical displays in which the user can see his/her designs in order to visually create and/or make changes to the designs. This is not true with a spreadsheet! After students have finished, and during data entry, all they will see are numbers. If they do not have a good grasp of the terminology and science and mathematical concepts related to ship or boat design, then they will not know what these numbers mean. And if they do not understand what their numbers mean, they will, of course, be much more prone to making mistakes. This leads into the next phase, which describes how much ship or boat design knowledge is necessary to compete in the competition and where it can be found.

Necessary Ship-Building and Boat Knowledge

When I became involved in this competition, I knew very little about boats or ships. Well, the truth is I knew absolutely nothing about boats. I was actually “volunteered” into creating a team to participate in the competition. As you know, technology teachers are problem solvers! One of the first problems I had to solve was to find out who could help me. I immediately contacted the President of our Parent Teacher Association and asked her to request assistance from parent volunteers. Being in the Hampton Roads area of Virginia, I was sure there had to be someone who worked in the local shipping or shipbuilding industry who might be able to help. I was not disappointed. Imagine my elation when I discovered a student of mine had a grandfather who owned his own yacht-design company! Since that time his son, who worked in the family business, has volunteered his time to come in to my classes and discuss shipbuilding design concepts and terminology with my students. He also helps me in reviewing my students’ work to point out any deficiencies and offer suggestions for improvement. But, most importantly, he also helps my students to understand the numbers! Once they have completed entering their data (from Inventor) into the spreadsheet, he gives a presentation in which he discusses what their final numbers mean. Nautical concepts and terminology such as displacement, center of buoyancy, centers of gravity, trim, freeboard, and stability among others are all

discussed and presented to my students so they can understand and master their interpretations of their numbers. As mentioned earlier, this is where STEM reaches its pinnacle in the competition. Students learn to relate their mathematical models to science, engineering, and mathematical concepts. For example, a boat may have a negative trim. Unless the student comprehends what a negative trim means, he/she would not know that the bow of the boat is pointing downward in the water. If they do know what a negative trim means, they can make a design change to make the trim more positive and raise the bow of the boat higher. Another example is a student design having hull plates with 10-foot high vertical centers of gravity. Well, there really is no reason for a vertical center of gravity to be that high above a boat hull. The students discovered this and realized they had likely entered data incorrectly into the spreadsheet and they needed to go back and double-check their work. But if they did not comprehend what the vertical center of gravity was, that 10-foot number may have been meaningless to them, and the error may have gone uncorrected.

The spreadsheet is a mathematical model of the students’ boat designs, and the correct interpretation of the spreadsheet numbers after students have entered the data is critical. It will allow them to visualize how their boats will sit in the water and thus better use the design process to make necessary and intelligent design changes. I would recommend, if you have very little or no boat- or ship-design experience, that you find someone to help you teach your students these basic ship-design concepts and terminology associated with the competition. It will greatly enhance your chances of success, and it will lead to better boat-design packages. The sponsor of the competition, Newport News Apprentice School, will also be available to assist you in this area as well.

Summary

It is important to emphasize that the boat design competition is a challenging, rigorous, “real-world” engineering design activity for high school students. But it is also fun, and your students will be genuinely engaged for weeks while they compete in the design portion of the event. I’ve detailed some methods I have used the past few years to streamline the event and allow my students to compete at the highest level of the competition. I would like to point out to the reader that there are many ways to generate a solution to the problem. Other participating teachers and students have used 3-D modeling techniques that differ from mine and have placed high in the competition as well. The methods I have shared here are certainly not the only way to go. I would

also like to point out, as with anything, the more experience that you gain, the more proficient you will become toward a successful competition. It has taken me several years of participation to develop my methods. But every year, students always seem to surprise me with their imagination and creativity, and as a result, new challenges emerge. For me, that's the fun part of teaching, and I hope you find it fun as well! Please feel free to contact me at jhammons@ycsd.york.va.us with any questions you may have.

The author would like to thank Bill Boze, Marine Engineer at Huntington Ingalls Shipyard, Doug Blount, owner of DBLA Robotics, Inc. and parent volunteer, and Dr. Walter Deal, Old Dominion University, for their assistance in writing this article.

References

ITEA/ITEEA. (2000/2002/2007). *Standards for Technological Literacy: Content for the Study of Technology*. Reston, VA: Author.

SNAME Boat Competition. Retrieved from www.sname.org/SNAME/DesignCompetition/Home/Default.aspx

SNAME Facebook Page. Retrieved from www.sname.org/SNAME/DesignCompetition/Facebook/Default.aspx

Virginia CTE. Engineering Drawing & Design, Virginia's CTE Resource Center (8436). Retrieved from www.cteresource.org/cpg/program_areas/52/courses/2394

Virginia CTE. Introduction to Engineering, Virginia's CTE Resource Center (8490). Retrieved from www.cteresource.org/cpg/program_areas/52/courses/2408



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