2006-2151: PADDLING FOR A RECORD—BUILDING A KAYAK TO IMPROVE CAD SURFACE MODELING AND COMPOSITE CONSTRUCTION SKILLS

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Abstract

This paper describes an advanced CAD course that used a kayak design project to engage students in developing their design, surface modeling, and composite construction skills. Students worked with a client, a competitive kayak racer, whose large size and personal goal to set a twenty-four hour distance record for a kayak presented both design and construction challenges. Students used an integrated CAD and CAE environment and met with other kayak users, designers, and builders to develop insight into the design challenges. While improving their surface modeling skills, students also combined requirements, manufacturing process knowledge, and an ergonomic CAE tool to produce hull designs. The students, assisted by their client and a local kayak builder, blended resin transfer composite molding with construction techniques from the Aleut Baidarka designs to produce the final kayak. The product created met the client's needs; it weighs twenty percent less than competing open cockpit kayaks and is six to ten percent longer.

Introduction: Advanced CAD and the Kayak Project Inspiration

An advanced CAD CATIA® course was offered on the authors' campus for the first time during the spring quarter of 2004. The purpose of this course was to improve students' surface modeling skills and proficiency within CATIA® Version 5. During the Advanced CAD course, students experienced the design process using an integrated suite of Computer Aided Design (CAD), Computer Aided Engineering (CAE), and Computer Aided Manufacturing (CAM) applications for digital product definition and simulation.[1] Teaching students about the integrated suite of CATIA within the context of the design process offered a few challenges. Text books on CATIA® V5 focus on introductory level skills in the solid modeling domain.[2] Several tutorials provide surface modeling exercises for students. The texts reviewed for the course did not integrate surface modeling within a top down design approach or with other workbenches in the CATIA suite of tools. These challenges were addressed by using a problem-based learning approach built around a client design project.

The authors chose a kayak design problem for a real client to help motivate students to improve their design skills. Our campus is located within a vibrant kayaking community. Olympic Gold medal winners can be found at the weekly match races on a local lake. The world's fastest surf-ski kayaks, the Twogood Mako® series, are hand fabricated a few miles from campus. Both Ocean® Kayaks and Necky® Kayaks are designed locally. Brandon, our client, paddled with his wife around Lake Baikal, the largest lake in the world. The pair won a stormy race around Michigan's Lower Peninsula. Brandon has also won the Yukon Quest event. Our client is preparing to set two twenty-four hour distance records held by kayaks on both moving and still water. His enthusiasm and energy became an inspiration for the course and the students.

The kayak problem enabled students to experience the design tool integration within the context of a real design problem. The Advanced CAD course used the kayak project to build upon students' existing design skills. The prerequisite Engineering Design Graphics (EDG) courses introduced students to fundamental skills in the area of visual communication, creative problem solving, project management, teamwork and self-learning skills.[3] Students became familiar with constraint-based modeling applications by following a workbook. Concurrently, they worked on design projects within the course that require the skills discussed in class. For the Advanced CAD course, the authors wanted the students to experience the design process with a real client, prior to our senior project capstone course. The lack of a suitable text benefited students by forcing the authors to follow a Problem Based Learning model more closely. The authors attempted to provide tutorials on specific skills as soon as students identified the need to have those skills. For example, students measured an example kayak and developed ideas for how hulls should be shaped prior to learning how to construct the hull design in CAD. Students also measured the client prior to learning how to operate the ergonomic tools available in the CAD package to create a manikin. In this way, students utilized the integrated product development tools within the engineering design process. The culmination of the design process resulted in the creation of several hulls and a completed kayak.

Design Project

The authors structured the team design project around Brandon's quest. The kayak project offered some advantages for improving student's design skills at an undergraduate, non-capstone level. Brandon was both the client and the user of the product. This fact reduced some communication and requirement complexity. The close proximity of the kayak community allowed students to "immerse themselves" in the design process and thus improve their chances of producing a creative solution.[4] The contact with kayak designers and builders enabled the students to be engaged in the process. The kayak itself provided a shape that is ideal for learning about surface modeling. It is a potentially complex shape, but may also be simplified without losing its characteristic appearance or function.

The students followed a design process as outlined in Dym and Little (2000).[5] Client requirements were gathered and parsed into lists of objectives, functions and constraints. A two stage benchmarking exercise provided additional design input. Concept designs were produced using the surface modeling tools. Following the course, several students undertook a reverse engineering process to provide the basis for final product creation—a kayak ready to go the distance.

A leading kayak builder, Sterling Donalson, met with students to discuss kayak design and construction. Students gathered requirements, including learning how paddling technique affects the hull shape. Students measured the client's physical joint lengths. The anthropometric data was used to construct a math model manikin to enable the students to design the hull around the client. As part of a benchmarking exercise, two racing kayaks were provided for students to measure and analyze. Students compared section data from each hull form to generate a baseline for their own designs.

A second benchmarking exercise involved touring the local Necky® and Ocean® kayak facilities to view how retail recreational kayaks are manufactured, marketed and sold. In addition, the students learned about high performance materials for composite kayaks from an aerospace composite material expert. These meetings provided students with motivation to tackle their team design projects.

Specific Design Requirements

The client's needs provide for unique design requirements relative to other racing kayaks. Requirements such as the client's large size, the required flat water conditions, and the 24 hour time period encourage novel solutions in terms of kayak width, length, stability, upper deck design, and materials. At nearly two meters in height and over 100 kg, the client is physically larger than the average kayaker. For Brandon, regular racing kayaks are not large enough in the cockpit area. In addition, these kayaks do not have sufficient buoyancy and tend to provide less stability for larger paddlers.

The experts and benchmarking exercises indicated that distance racing kayaks were generally between 6 and 6.5 meters in length. Longer boats have a higher potential hull speed, at the expense of greater weight, and a larger surface area for increased surface or skin friction drag. Predominant ocean conditions and particularly average ocean wave length have led designers to limit overall kayak lengths. A longer boat may be faster in a tow tank, but not under paddling conditions in ocean waves. However, the river or lake conditions for the distance record will not include ocean waves. This may allow a practical boat length of up to 7 meters for greater hull speed.

Distance ocean racing kayaks currently follow a surf ski design practice. The surf ski hull does not have an enclosed cockpit. Instead, the kayaker sits in a molded open form on top of the hull. The design offers at least two key advantages over an enclosed hull. One advantage is that the hull can be narrow to reduce water drag, as narrow as 30 cm in some sprint racing designs. A second advantage is that the boat is easier to climb aboard should the kayaker fall off. The ability to climb onto the kayak becomes critical in an ocean environment with large waves. Although the narrow boats are less stable, the races are shorter and the elite kayakers manage the instability.

The client's desire to paddle in daylight dictates a northern latitude to enjoy nearly twenty-four hours of daylight. The open cockpit advantage in a tropical ocean environment becomes a liability in the cool ambient temperatures of the far north. For a twenty-four hour record attempt, the client felt that an ultra narrow boat would not be stable enough. These two factors led to the selection of a closed cockpit design with a 45 cm maximum hull width. The closed cockpit design coupled with the increased length and width provides an additional 36 kg of buoyancy over a competing surf ski design.

Modeling Process

Students used surface-based modeling techniques to complete their concept designs. The modeling process followed instruction on core surfacing skills such as wireframe feature construction and complex surface construction. The kayak specific modeling process involves creating planes at key intervals along a desired design length. Sketch profiles of hull station contours are added to each plane. A blend feature is used to generate surfaces between the sketch profiles (Figure 1). The kayak ends are closed using a fill command. Individual surfaces are joined command. The surface is converted to a solid (Figure 2). A shell command hollows out the hull to the desired design thickness.

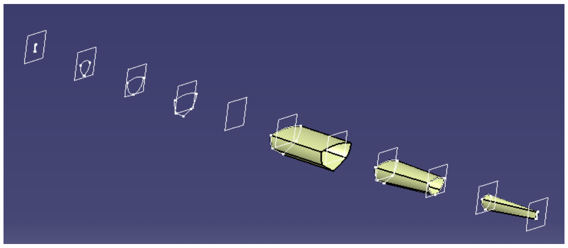

Figure 1. Sketch profiles on planes and join.

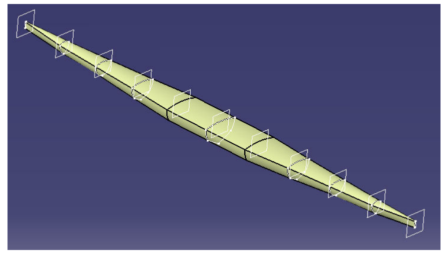

Figure 2. Convert surfaces to a solid.

The cockpit is generated by creating a sketch on the top surface of the hull. The sketch guides a pocket command to remove the cockpit profile from the hollowed hull (Figure 3). Bulkheads are created to separate the cockpit from the rest of the boat (Figure 4). The ends of the kayak may be finished with a cylinder. A complete design with a manikin of the client is shown in Figure 5. The kayak shape allowed students to develop their skills for creating splines, swept surfaces, lofted surfaces and blended surfaces.

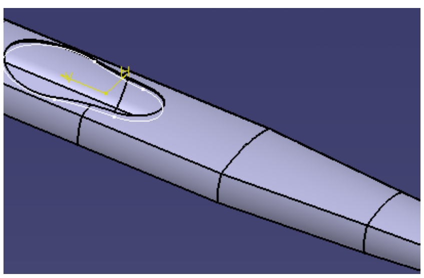

Figure 3. Creating cockpit opening.

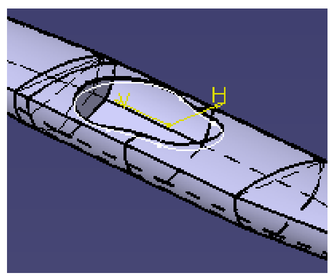

Figure 4. Cockpit bulkheads.

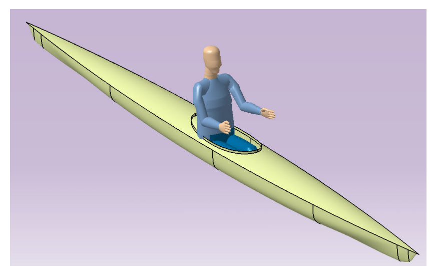

Figure 5. Manikin.

Mold Construction

Following the Advanced CAD course, students began to build a physical hull based upon their design experiences. Building the final kayak hull involved creating several intermediate products—creating a temporary mold, a plug, final mold, and then a kayak hull. The last two steps were repeated to improve the final product. The temporary molds were created from the client's existing kayak. These molds allowed the rapid construction of a base plug. The plug was then extensively modified to create the desired shape. Students created two temporary molds. One mold was taken from the bow to approximately 30 cm past mid-length. The second mold was taken from the stern to approximately 30 cm past mid-length. The points past the existing kayak's mid-length mark were chosen so that both molds would have the same width and general contour when the molds were joined. The molds were arranged so that their overall length was nearly 7 meters—6-10% longer than competing surf-ski designs. The molds were then joined (Figure 13) and prepped for the creation of a splash plug.

The temporary mold construction followed practices used in our composites facilities on campus. The existing kayak was washed, waxed with five layers of composite tooling wax and then sprayed with a water soluble release agent, polyvinyl alcohol (PVA). A tooling polyester resin gel coat was applied to the kayak surface. Students and the authors practiced a different technique for applying the gel coat on each mold—spraying and brush application. Following the second application of gel coat, strips of fiberglass veil were placed on the gel coat and wet out with polyester resin. Two layers of fiberglass mat were placed on the veil and wet out with resin. Reinforcement with heavy fiberglass added stiffness to the mold.

The mold was prepared to create a plug, which would provide a form to support the final shape of desired kayak design. The desired bow form and contours were added to the plug to create a smooth contour from bow to stern. The plug was created by first washing, waxing and spraying the mold surface with PVA. Black tooling polyester gel coat was applied to the mold surface. Strips of veil followed by fiberglass mat were wet out on the mold surface. After the plug cured, the plug was removed from the temporary mold.

Figure 13. Temporary Mold

Figure 14. Shaping the splash plug.

Body filler was used to shape the plug (Figure 14). A clear urethane coat sealed the body filler. After waxing and PVA application, black tooling gel coat was brushed onto the surface in several thin layers. The process for adding veil, mat and reinforcement material was repeated to create the final mold. The first mold was rejected due to pin holes and a poorly shaped bow. Prior to construction of a second mold, the plug was reshaped to improve symmetry and the bow shape.

A vacuum-assisted resin transfer molding (VARTM) process was selected to produce the final hull. The VARTM process is a closed mold process where dry reinforcement fibers are placed in a mold. Bagging material seals the mold and a vacuum is drawn. Resin is introduced via feeder tubes into the mold. Capillary action and vacuum pull the resin through the part and wet out the reinforcement fibers.

The VARTM process offered several benefits. Since it is a closed mold process, students are less likely to be exposed to harmful epoxy resins. Second, the process has become the standard method for high performance kayak construction. Properly done, the process offers good fiber volume ratios without the capital and handling expense of autoclave and pre-impregnated carbon fiber construction. The process is suitable for very large structures with much higher quality than a wet lay-up technique. Finally, the local marine and aerospace industries that hire our graduates have recently adopted this process.

Four hulls were created to achieve a final part with the desired quality, shape, stiffness and mass. Both infusion grade vinyl-ester and epoxy were tested. The epoxy provided a longer working time and was therefore more forgiving to mold preparation and bagging errors. The final hull uses a 3k tow, carbon fiber twill fabric woven from Toray T-300 fibers. The hull is unusual in that only two layers of the fabric are used. The layers are separated by a new type of core material, Soric®. The core material acts as both a stiffening element and medium through which resin travels. The bare 7.0 m hull weighs 4 kg out of the mold, including gel coat.

The advanced carbon composite hull joins with a stretched fabric upper deck reminiscent of Aleut Baidarka boats. The hull edges or gunwale were reinforced with red cedar strip. The cedar provides an attachment point for the fabric upper deck. Cross hull reinforcements of carbon fiber and Nomex honeycomb core prevent the gunwale from buckling. Soar Coat silicone impregnated rip-stop nylon is stretched and stapled to the lower, rigid hull. The unique upper deck and lower hull construction contribute to an 7.7 kg boat mass, roughly twenty percent less than competing designs.

Results

The kayak project provided a means to motivate and excite students about surface modeling CAD techniques. The students chose to spend long sessions with the experts. The project met the authors' objectives for helping students develop their surface modeling skills. Surface modeling was not taught as a formal course prior to the Advanced CAD course. However, in the past two years, more than ten percent of our students have obtained jobs that require some level of surface modeling proficiency. The kayak construction phase introduced many students to practical composite techniques and the VARTM process. More than forty percent of our recent graduates are working with companies that use the VARTM process to produce composite molds, aerospace components, and marine hulls. Several students used the VARTM process to produce a series of vehicle chassis components during the summer of 2005. Finally, the completed kayak hulls are significantly lighter and longer than competing design. The client plans to attempt a record in April, 2006.

Conclusion

The use of the kayak project with guest speakers and tours added an exciting element to the Advanced CAD course. The client-focused project provided students with a strong incentive to learn about surface modeling techniques and design methodologies using an integrated suite of design tools. Evidence for the students' enthusiasm for the course was demonstrated by their hours during the design process. The physical construction of the kayak provided many students with an application to develop their composite construction techniques. Several first and second year students learned to build composite molds. The authors believe that the kayak project provided a unique challenge to students to help them improve their product design skills.

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