The Application of Advanced Product Development Techniques to a 1st Year Engineering Student Boat Design Project

A thesis submitted in partial fulfilment
of the requirements for the degree of
Masters of Engineering
in Mechanical Engineering

by

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Abstract

The design and manufacture of a RC model boat is a component of the compulsory paper ENGG180 for first year engineering students at the University of Waikato. ENGG180 is a foundation of engineering paper which includes project-based learning, fundamental principles of engineering design and engineering analysis. The model boats made by undergraduate engineering students are rather primitive in design and use conventional manufacturing methods.

The conventional methods used by students, to make the hulls are a very labour intense and inaccurate. In the present method there is no direct link between the CAD model and the manufactured hull due to the absence of computer-aided machining. However using conventional methods, students get more knowledge on how parts are manufactured.

These conventional methods of fabrication are used because the primary emphasis for their project is experiencing the design process, working effectively in a team and working to constraints (such as time, money and materials). The current emphasis is not fabrication technologies. Students would gain more accurate impressions of design and fabrication if more up-to-date technologies were demonstrated.

The purpose of this research is to teach students about the designs and features of a fast boat, modern manufacturing methodologies and rapid prototyping. The boat was designed in Solidworks, the hull mold was machined using a CNC milling machine directly from the CAD model. The many internal pats were produced with laser cutting machine from the CAD model. Thus the model boat was built accurately to the CAD model. These methods demonstrated have modern CAD and CAM techniques which could be successfully applied to the manufacture of model boat.

It was found that the boat did not perform as expected this was due to problem with battery performance. It is therefore suggested that if further work be undertaken in this area more detailed modelling and simulation (CAE) of the boat system be carried out.

Acknowledgements

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Symbols and Abbreviations

Symbols

A	-	Ampere
W	-	Watts
Nm	-	Newton meter
RPM	-	Revolutions per minute
N	-	Newton
V	-	Volts
Wh	-	Watt hour

Abbreviations

PBL	-	Project-based learning
CAE	-	Computer-aided engineering
CAD	-	Computer-aided drafting
CAM	-	Computer-aided machining
CNC	-	Computer numerical control
MDF	-	Medium-density fibreboard
LOA	-	Overall length of the boat
LWL	-	Waterline length of the boat
RP	-	Rapid prototyping
SLA	-	Stereolithography
LOM	-	Laminated object manufacturing
FDM	-	Fused deposition modeling
SLS	-	Selective laser sintering
NiMH	-	Nickel metal hydride
CO_2	-	Carbon dioxide
DC	-	Direct current

Chapter 1 Introduction

At the University of Waikato, first year undergraduate engineering students from all the engineering streams i.e. Biochemical Engineering, Electronics Engineering, Materials and Processing Engineering, Mechanical Engineering and Software Engineering take a compulsory paper ENGG180 (Foundations of Engineering) as part of their curriculum. This paper covers many areas including Project-based Learning (PBL). The paper provides an introduction to the engineering profession and the role of engineers and technologists in shaping technology in the past and present. It also covers fundamental principles of engineering design, PBL, open-ended problem solving, engineering analysis, engineering accounting of mass, energy, entropy and money.

1.1 Project-based Learning (PBL)

Project-based learning is an instructional strategy designed to motivate students in investigation of authentic problems and reflect on their experience to understand more on what they are doing, instead of being just result oriented and focusing on getting it done. Knowledge is improved by solving a complex problem, to reach the solution students ask questions, make predictions, debates, make design plans or do experiments and exchange ideas there by acquiring an understanding of key principles and concepts. Hence projects help develop deep understanding as students need to acquire and apply information (Blumenfeld et al, 1991). Project-based learning gives opportunity for the students to connect their knowledge, values, attitude and skills by working in a small team on academic projects (Lam et al, 2009).

"When students are challenged to get to work solving real-life problems, the whole world becomes a classroom (Solomon, 2003)".

Conventional classroom teaching helps student learn curriculum but lacks in practical knowledge while projects gives opportunity to investigate and seek solutions for the problem, there by acquiring an understanding of key principles and concepts. It also helps in reducing the so called gap between classroom teaching and real life problems. Projects involve students gathering data from different sources, make use of latest technologies by which they can gain/share information, even with the outside world apart from the classroom, thereby providing an expanded view of the subject matter (Blumenfeld et al, 1991).

Teachers design the projects, which are interesting, motivational, and meaningful, providing deep level of understanding to students. Projects can also increase student interest as it involves solving authentic problems by working in groups and helps build real solutions (Blumenfeld et al, 1991).

“PBL is one of the most interesting, efficient, and meaningful ways to cover the curriculum, teach the standards, and address individual learning styles” – Bernie Trilling, director of technology in education, WestEd. (Solomon, 2003).

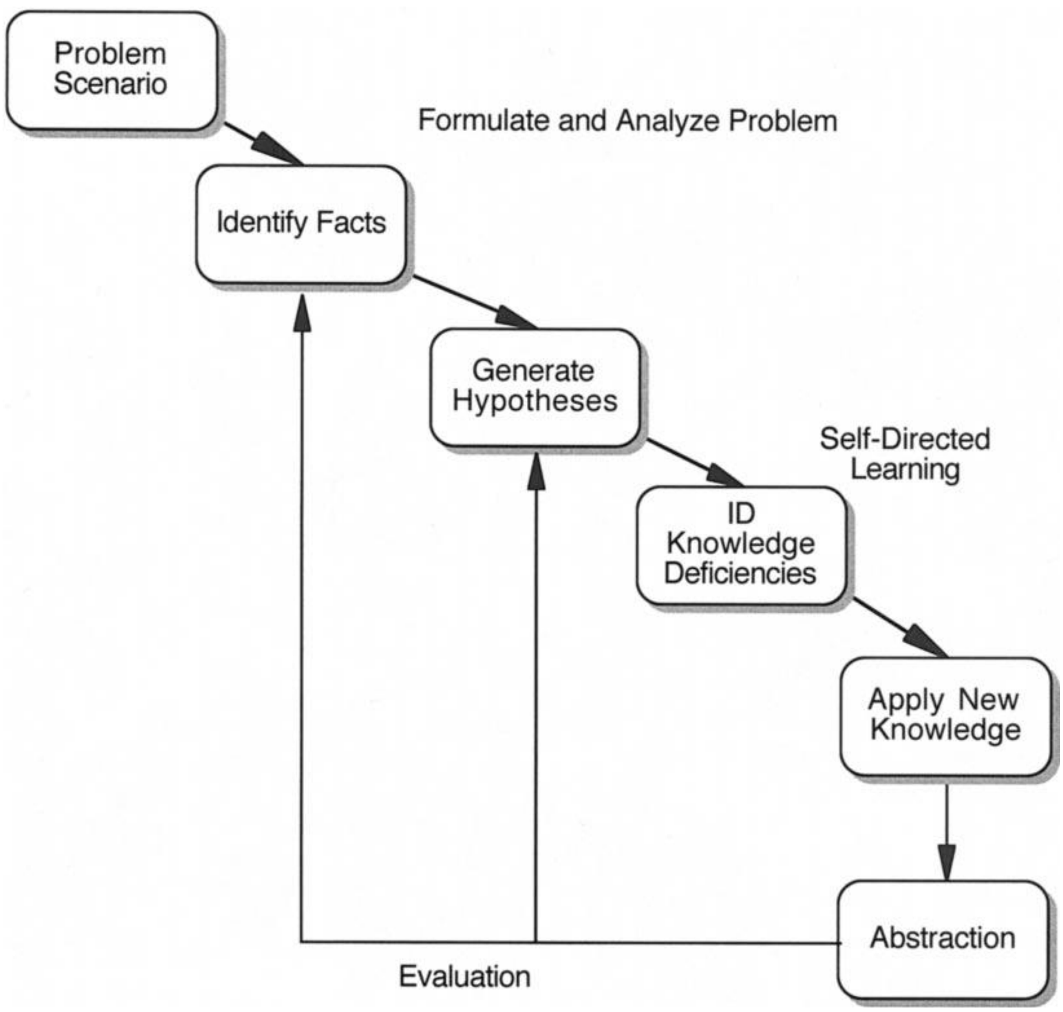

Fig. 1.1 The problem-based learning cycle (Hmelo-Silver, 2004).

Teachers present students with a problematic scenario, which they formulate and analyze by identifying the relevant facts which are vital for the better understanding of the problem. This helps students to generate a hypothesis of the possible outcomes. The step is identifying the knowledge deficiencies, which are the learning issues that students research during their self-directed learning. Then, new knowledge is applied to evaluate their hypothesis. Teachers help and guide students to acquire the cognitive skills needed to solve the problem. Figure 1.1 shows the problem-based learning cycle (Hmelo-Silver, 2004).

"Because students perform activities that are valued in the real world, manage their own work and time, and are part of a team, they learn 10 times better than in a traditional process." – Bob Pearlman, director of strategic planning, New Technology Foundation (Solomon, 2003).

1.2 Learning outcomes of ENGG180

Students who successfully complete the course are expected to:

- Know the difference between science, engineering and technology.
- Understand, through experiential learning, the engineering design process
- Recall the general 'accounting' equation and be able to solve appropriate problems where this is applied to accounting for mass, energy, entropy and money.
- Explain how expert problem solvers operate and be able to use heuristic methods in problem solving.
- Appreciate the influence management practices can have in determining the economic success of engineering projects
- Realise the importance that engineering fundamentals have in solving real-world problems and be able to solve appropriate problems.

Since the project involves students from all the engineering streams and not mechanical alone, the emphasis is given on team work, working to constraints, effective communication and interpersonal skills which makes the model boat rather primitive in mechanical design and efficiency. Though the boat hull is designed using design software (Solidworks), the mold for the hull is cut and shaped from polystyrene manually without employing modern machines, resulting in inaccuracy of the hull shape. These boats also lack performance due to increased drag, poor design, and improper distribution of weight of the internal parts.

1.3 ENGG180 Boat Project

The students are randomly picked to form syndicates of 6 to 8 members by the staff. They are also assigned with a project manager from the final year to manage the syndicate, which is explained in chapter 2. The syndicates are given the project to make remote controlled boats, which are finally raced on a race day. Each syndicate have to make 2 model boats for which a time limit of five, three-hour lab sessions to manufacture and assemble the boat and another two hour for painting is given. All syndicates must follow a strict set of rules including budget.

1.4 Project Objective

The purpose of this project is to educate students on how to make the same model boat more efficiently using latest methodologies and boat design principles.

Chapter 2 Project Based Learning and ENGG180

As already mentioned in the previous chapter, ENGG180 is mainly a project-based learning paper. This chapter discusses about how the boat is made by the students and how this paper acts as a project-based learning paper.

By successfully completing the ENGG180 paper students learn soft skills and few basic hard skills necessary for an engineer.

2.1 Soft Skills

Modern engineering activities not only demand technical skills but also a high level of soft skills. Soft skills are those non-technical skills and the general personal qualities required for an effective professional practice (Johnston & McGregor, 2005).

In real life, the design and construction of a project is the responsibility of the organisation. The organisation consists of engineers who are in charge of delivering the completed project to the required standard and conditions within the time limit. Within the organisation, engineers work together in a team instead of working by themselves, which requires soft skills such as accepting responsibilities, helping and co-operating with others, good communication skills, following rules and regulations, commitment towards their work and organisation etc (Ling et al, 2000).

These days most employers prefer a workforce which can excel in softer skills especially working in a team and group development. The employers expect the workforce to learn these soft skills during their studies or through work experience (Pant & Baroudi, 2008).

Due to the high demand of soft skills in recent years by industry, the model boat making project is more focused on soft skills compared to hard skills. Also since the students involved in the project are from various disciplines, giving greater emphasis to hard skills would only be beneficial for a few. Some of the soft skills learned during the course are:

- Team work

- Working to constraints
- Communication skills
- Writing skills
- Problem solving skills
- Design process
- Project management

2.1.1 Team Work

A team is a small group of people with complementary skills assigned for a common purpose and performance goals. The ability to understand and identify the distinct strength and skill of the members in the team which can be effectively applied to find a solution is known as teamwork. In many organisations team work has become a primary aspect as a team can take more pressure as compared to an individual, work at a faster rate with increased productivity and quality (Levi & Slem, 1995).

One of the important objectives of this paper is to teach the students to work in team to begin developing team working skills. A task can be done faster when in a team than as an individual because large tasks can be split into smaller portions and assigned to the members appropriately, based on their skill and knowledge which increases the creativity and efficiency of the team, particularly when considering a task which requires a variety of capabilities, judgement skills and experience (Barak & Maymon, 1998).

Once the team (syndicate) is formed they fix a weekly schedule with their project manager to discuss the project, and also to interact and become familiar with each other. Information is shared about their skills and knowledge which can be applied effectively to accomplish their task. This helps the members to know more about each other and their differences, by which they can firmly decide on how they will work together. The project manager is selected from the final year with a previous experience of the model boat building and can guide the syndicate effectively.

The model boat building is subdivided into smaller sections of CAD drawing, hull designing, steering, propulsion and finance so it can be managed more effectively. The project manager allocates these tasks to the members depending on their capability to accomplish the work, so that all the tasks can be carried out simultaneously without wasting time. When a subdivided group of two members are working on the mold for the hull, two can work on the steering system and others can work on the electrical or propulsion system and one person to manage all the finance. They are aware of their role and responsibilities and strive to work together under the guidance of the project manager. Any disagreements or misunderstandings while working are handled effectively to complete the project successfully. This way the students learn to work effectively in a team to achieve the goal. Also the project managers who are final year students get a chance to manage the team and also improve their skills.

2.1.2 Working to Constraints

There are boundaries set for the project that the students must work within. The constraints they have are: time, budget and restricted material use. These constraints teach them the following:

- Time management
- Budget management
- Right material selection

Time Management

The activities that contribute to the effective use of time, which is considered to accomplish a task and diminish stress, are known as time management (Zampetakis et al, 2010). The positive outcomes of effective time management on employees are less work related stress and hence more job satisfaction (Macan et al, 2010).

Time is an important factor in any project, to manage the time effectively the team first need to have a goal, which obviously is to build two model boats in the limited time given. The time provided for building the boat is five 3-hour lab sessions. By setting the goal or target students apply more effort and become attentive and interested in their work with well organised working habits. The most common feature of the concept of time management is planning behaviour which defines the tasks to perform and their prioritization, which is a particular method of goal setting (Zampetakis et al, 2010). A detailed plan is made on how the boat and its parts are to be made according to which jobs are prioritised and allocated to the members. The ideas are generated by the members. The project manager guides them to effectively implement their ideas and monitors their progress.

Budget Management

The purpose of a budget is to control the project cost and for a project to be successful it has to be within the budget. Each syndicate has a budget of $340 from the sponsor’s store for the materials to manufacture the boats. The materials to be used are supplied from the sponsor’s store and their prices are given in the Appendix 2. Sponsor is the technical officer who supplies the material. Each syndicate has 2 orders per session, one pre-order which can be placed a week before the build session or latest by 4:30pm of the day preceding the syndicates build lab. This allows students to start work straight away and reduces stress for lab technicians. The second order is an ‘in-session’ order so they have an opportunity to order more materials they may not have realised they needed or are required for a new task. Any return of goods bought will have a restocking fee of 15% of the list price to the syndicates account.

A rough budgeting is performed at the initial stages of project planning and also in parallel with the development of the project. To make a rough budget demands a proper planning of the materials to be used. This system helps students learn to work to a budget.

Material Selection

The materials required for the model boat building are provided by the ‘sponsor’ and has a direct impact on the budget. Moreover the students are supposed to use only the materials and tools available in the order form (Appendix 2). Since the availability of the materials is limited, care has to be taken while designing the boat such that they can build with the available materials within their budget. Since there is a 15% restocking fee for the materials returned to the sponsor the syndicate have to be certain about the items they need and make sure there are no excess items bought. This encourages them to work within the limited resources available.

2.1.3 Communicative Skills

Effective communication between the team members plays an important role in achieving project success. Team members need to communicate well with each other at each and every stage of the project development so that there are no conflicts or mis-match of the ideas developed by individuals. In this technology oriented world, findings indicate the role of communication both written and oral has become more important than ever before, and lack of communication is one of the greatest risks affecting the success of any project (Chen et al, 2005).

The model boat building project is a set of related activities aimed at achieving the goal of producing the best boat for race day, achieved by 6 to 8 members in the team. To succeed in their goal there has to be an effective communication among the members and the project manager from the very beginning of the project development. Effective communication is vital during project planning, comparison during execution of parts made, making decisions and updating plans. Communication is said to be effective when there is proper exchange of data and information among the members (Blankevoort, 1984).

The idea is that effective communication behaviours will enhance the selection of materials, specify requirements and evaluate the progress made. Effective communication during the development and manufacturing can bring positive results, improved productivity and satisfaction while lack of communication can have a negative effect on the project, causing mismatch in the design, manufacturing of incompatible parts, exceeding the budget, buying excess materials etc.

2.1.4 Writing Skills

Writing is an important tool for communication for engineers. Engineers are professionals who hold a higher post in the company or work as consultants. Their work routinely consists of interacting with clients, employees and higher management people where there is the need for regular report writing and proposals which require highly developed writing skills. Engineers also need to write formal reports about their project's development for clients and upper management. Engineers are always developing new innovative ideas, to express these ideas effectively to others demands good writing skills (Zhu, 2004).

Studies indicate that 80% of an engineer's work time is spent on communication. The writing ability of engineers is indicated as the most important skill in evaluating their success (Ostheimer & White, 2005). Communication skills are considered to be the most important skills needed for success in a professional career, with technical writing skill rated high (Jenkins et al, 1993).

Once the boat is built and raced, the students are expected to write a detailed report on the project. The report should consist of the design they choose for the boat and the reasons for their selection along with the technical aspects. The contribution of each member towards the building of boat, the performance of the project manager and his management techniques and how helpful was it for the team. A performance appraisal has to be made on the boat, whereby the syndicate and the project manager evaluate their performance as a team. This report writing gives them an opportunity to improve their writing skills and be beneficial for their following years of study.

2.1.5 Problem Solving Skills

A problem in this context is defined as something that happens differently than was expected. Problems often occur in industry while working on new projects. It is often seen that graduate engineers are not capable enough to solve the problem quickly, which leads to a delay in project completion time, loss of money and market share (Maul, 1996). This has been a matter of great concern to industrial managers. The lack of problem solving ability in graduate engineers is because, at in school they are taught in a controlled manner within text books. Their exposure is limited to the classroom and their knowledge is limited to theory, giving less exposure to practical problems. Text book problems are well structured while work place problems are ill-structured (Maul & Gillard, 1996).

Through this model boat making project the students learn about the practical sides of the projects, the problems encountered at each and every stage of project development for which they have to find solutions through team work. Some of these problems may be ill-structured i.e. there will be lack of data to solve the problem for which mere logic or common sense have to be applied to find the solution. These experiences help them develop problem solving skills.

2.1.6 Design Process

Figure 2.1 shows the pugh design process taught to students during the lecture. The design activities start from the market, researching the need for design and its specifications. Concept designs are made and the most appropriate design is selected for detailed designing. A prototype of the design is made and manufactured.

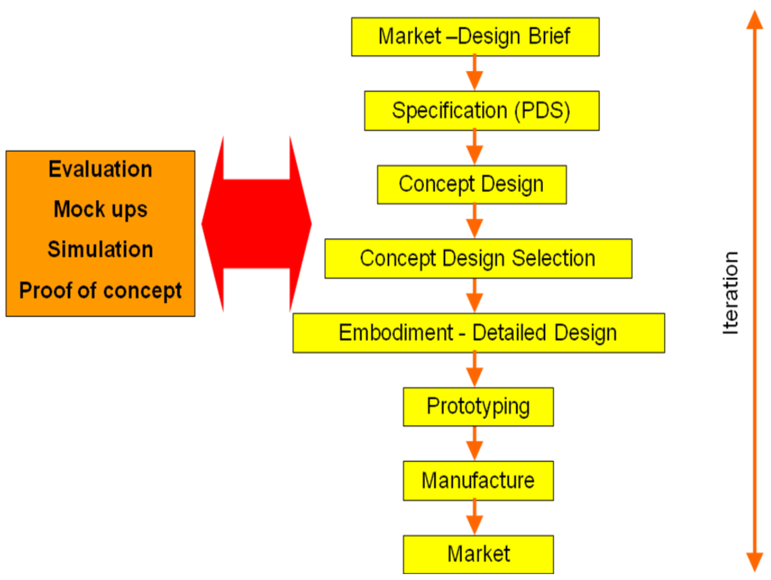

Figure 2.1 Core activities of design process (source ENME480)

2.1.7 Project Management

Each syndicate and their project are managed by a project manager from the final year. The final year students who work as project managers for the first year's model boat making project are exposed to project management with the aim of them learning good project management skills.

Characteristics of Project Manager

The person should have knowledge about each discipline to understand the overall problems encountered and find a solution by discussing it with the other team members. They should be an effective problem solver and decision maker who has a good judgement capability and common sense. They should possess thorough knowledge about planning, supervision, budget and follow-ups. They should be a good motivator who can motivate the team members to achieve their goal and flexible enough to adapt to changes. They should also be logical and dedicated. (Pettersen, 1991). These skills cannot be taught in classrooms but can be learned only through experience.

2.2 Hard Skills

The hard skills learned during this project are:

- Introduction to CAD
- Basic workshop skills and safety
- Knowledge of model boat construction and performance
- Familiarity with vacuum forming

2.2.1 Introduction to CAD

Students are exposed to a CAD package called Solidworks to develop a set of engineering drawings of the boat hull and its compartments. By successfully completing the 3D drawing in Solidworks they get familiar with the features and the tools available in the package.

CAD is used early in the design process to model the boat and its components; this allows them to improve their design ability, problem solving skills and creativity. Creativity in this context is defined as the creative problem solving ability in engineering design (Robertson & Radcliffe, 2009).

By using CAD the students are able to provide a visual model of their boat design and its components, the visual expression is a vital factor for the generation of new ideas for product development, it also acts as medium for communication and cultivating the syndicate's idea generation process (Lugt, 2000).

The exposure to CAD software in the very first year of the studies gives them the opportunity to improve their design skills and knowledge of engineering drawing for their future course of study especially when working on more complex design projects during their final year, and also later when employed in industries where there is a high demand for design engineers at present.

2.2.2 Basic workshop skills and safety

The building of the model boat involves the use of number of hand tools and power tools which if not used properly can cause injury to the person using them or other people. The students are taught how to use the tools and the safety measures to be taken while using them.

Hand tools are the traditional tools found in all engineering workshops. They are the main tools students use in lab when building the model boat. Hand tools are non-powered, easy to carry, and is supported completely or partially by the user's hand. Hand tools are probably the first man made items to cause injuries and even today are a common source of occupational injury (Myers & Trent, 1988).

Some of the common hand tools used in the lab are; hand saw, hammer, knife, pliers and screw drivers. These tools if not used carefully can cause severe hand injuries. These hand injuries are usually costly to treat and considerable amount of time gets wasted (Mackenzie & Peters, 2000). Figure 2.2 shows a student using a hand tool (cutting tool) to trim the deck after vacuum forming and Figure 2.3 shows the same cutting operation done by a power tool. Figure 2.4 shows a student using drilling machine.

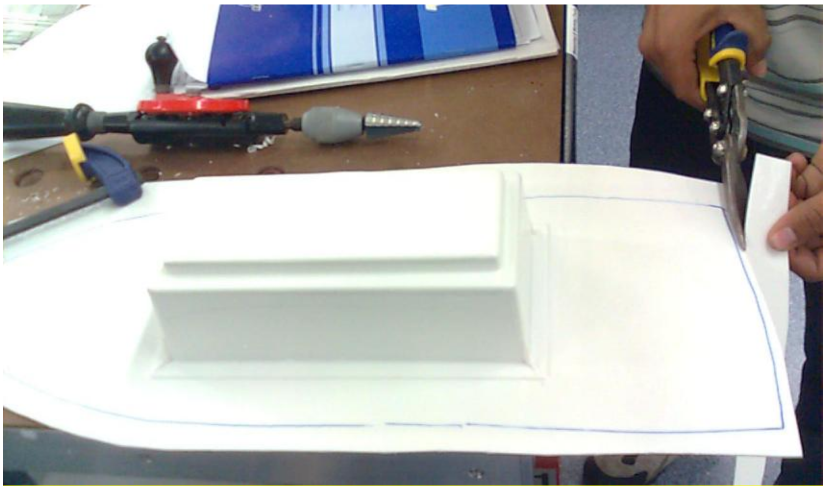

Figure 2.2 Using cutting tool to trim the deck

Figure 2.3 Using a power tool to trim the deck

Figure 2.4 Drilling operation

Accidents should be prevented, for which students should be aware of the possible hazards that could be caused by each tool if misused and they should be able to foresee the danger (Jorgensen, 2010). To prevent these accidents in the lab, students are taught about lab conduct and the precautions to be taken for a safe working environment. They are also provided with the necessary information to handle the tools and other safety precautions to be taken while in lab which is given in Appendix 3. Through this, students get good hands on experience with a range of hand tools and power tools.

2.2.3 Knowledge on boat construction and performance

Prior to building the boat students are taught about the construction, performance, features and different parts of the model boat, which mainly consists of:

- Hull
- Propulsion
- Steering
- Mold making

Hull

The top speed of the boat depends upon the engine power, hull shape, and wet surface area of the hull. The drag force caused by the water around the hull is known as the hull drag.

Earlier in the semester, hull drag experiments are conducted in the lab on some of the basic hull shapes to determine the drag coefficients at different water velocities. They also learn about different speed boat hull shapes and how the differences in shape affect the drag. Based on these knowledge students choose the hull for their purpose. Figure 2.5 shows the drag coefficient versus velocity graph of the hull models tested in lab by the students. The hull names in the graph are named according to their shape.

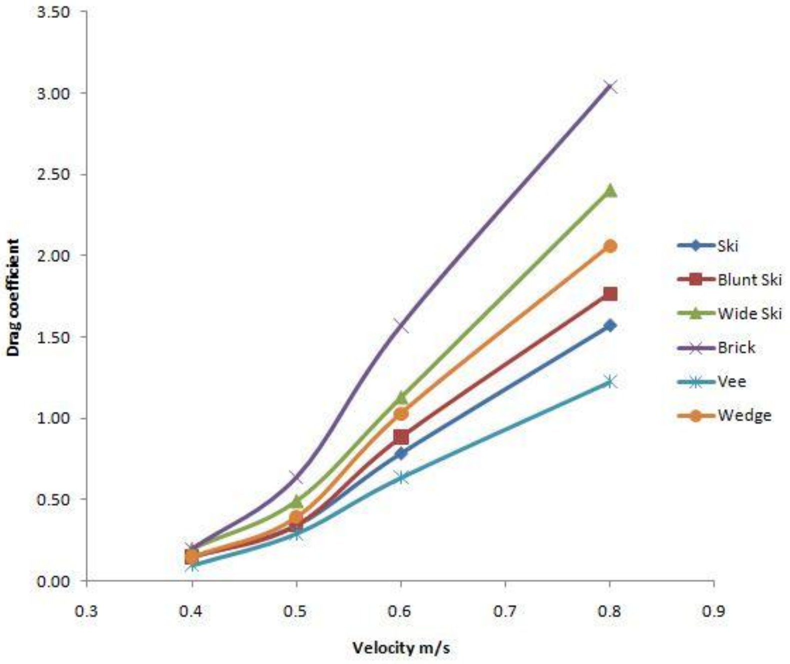

Figure 2.5 Drag coefficient versus velocity graph

This is a good empirical learning but lack in computer-aided engineering (CAE) and computational fluid dynamics (CFD) as it not appropriate for first years.

Propulsion

The propulsive system consists of:

- DC motor
- Propeller
- Batteries

DC motor

The mechanical force required to propel the boat is supplied by the DC motor. This DC motor is connected to the propeller using a shaft. The mechanical power of the motor produces torque on the shaft connected to it; this torque is converted to thrust for propulsion by the propeller connected at the other end of the shaft. The electrical energy to run the motor is supplied by the batteries.

Experiments are conducted in lab to learn the DC motor characteristics. The motor is supplied with varying voltages to determine the shaft torque, motor power, and overall efficiency of the motor. Based on this experiment graphs are plotted on torque versus rpm, motor power versus electrical power, efficiency versus rpm and voltage versus torque. From the graphs plotted, decisions are made on what is the maximum voltage and current required, which determines the number of batteries to be used.

Propeller

Model boat propellers are available in a wide range of diameters, pitchs and number of blades. Propeller selection is a very important aspect in boat design, for which students should have a good knowledge about propellers and how the difference in the dimensions affects the boats performance.

Propeller #	Diameter (mm)	Pitch
1	50	1.2
2	50	1.4
3	50	2.0

Table 2.1 Propeller dimensions

Three propellers are available for the model boat project from the sponsor as shown in the Table 2.1. Lab experiments are conducted with the three propellers to select the suitable one for their boat. The experiment is mainly to determine the effect of these propellers at different voltages. The force exerted by the propeller at different voltages, and the current drawn are measured based on which, they select the suitable propeller.

Batteries

From the graphs plotted with the above mentioned experiments, students decide the number of batteries required to propel the boat efficiently. From the experiments they get to know the current drawn by the motor at different voltages. This can be used to determine the voltage needed to be supplied to the motor.

Steering

The boat needs to be steered to change the course of direction this requires a rudder to be used. The movement of the rudder is controlled by a servo motor, which is controlled by a remote control unit. When under the control of the remote control the servo have approximately ± 30^0 range of motion.

The shape and size of the rudder is very significant. Some of the shapes available are rectangular, elliptical and wedge shape. The rudder shape is decided on the basis of drag created by different shapes. Drag coefficient is high for a rectangular shaped and least for the elliptical shaped.

The rudder is made of thick plastic. The rudder is first designed and drawn on the thick plastic sheet and cut out manually using a cutting machine. This is later shaped and smoothed for finishing (Figure 2.6).

Figure 2.6 Rudder

Mold Making

Mold for the hull is made of thick expanded polystyrene, layers of polystyrene are glued together to form a block of the required size, the outlines of the hull which is already designed in CAD is drawn on this block of polystyrene as shown in the Figure 2.7 and cut out using a hot wire cutter to become a prototype of the boat as shown in the Figure 2.8. Since this is a manual process the mold is usually cut to a larger dimension than required so later it can be sanded close to the required dimension. Once the mold is cut and sanded it is coated with three layers of white GIB compound as shown in the Figure 2.9 to make it heat resistant as this mold has to be vacuum formed to form the hull where the temperature is around 80^0C. Once the GIB is dried, one layer of coloured GIB is applied as shown in Figure 2.10 followed by another layer of white GIB. This when dried is sanded for a smooth finish. The purpose of the coloured layer is to make sure too much sanding is avoided i.e. to stop sanding the final layer when the coloured layer becomes visible. Figure 2.11 shows a mold being sanded and Figure 2.12 shows a finished mold ready for vacuum forming.

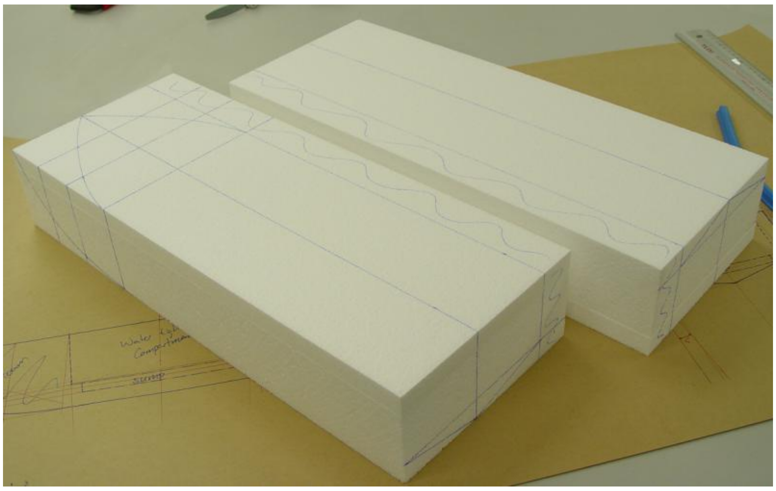

Figure 2.7 Polystyrene block marked for cutting

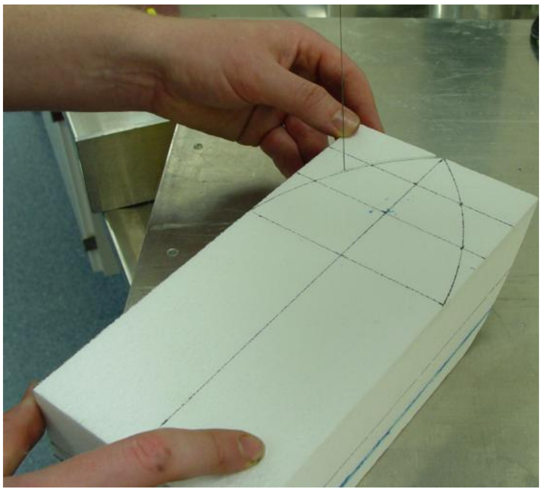

Figure 2.8 Cutting the mold using hot wire cutter

Figure 2.9 Coating the mold with white GIB compound

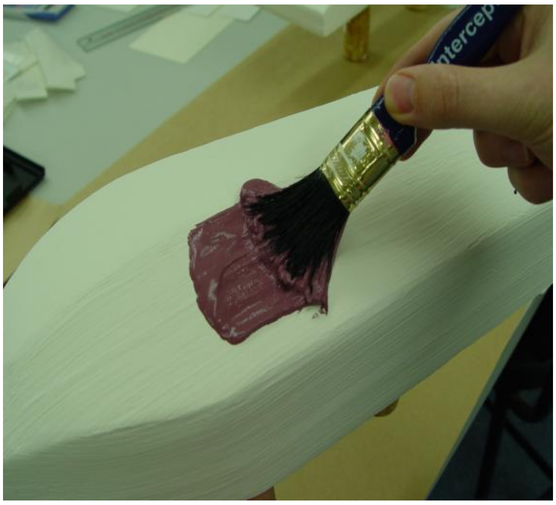

Figure 2.10 Coating the mold with coloured GIB compound

Figure 2.11 Sanding the mold for finishing

Figure 2.12: A finished mold ready for vacuum forming

2.2.4 Vacuum Forming

The hull for the boat is made from 1.5mm PETG sheet; this sheet undergoes a vacuum forming process to obtain the shape of the hull. Students are taught about the vacuum forming process, its advantages, disadvantages and applications.

Vacuum forming, a simple form of thermoforming, is a widely used method for processing plastic materials. In this process, a plastic sheet is heated and draped over a mold while a vacuum is applied. This is then left for some time to cool and later the plastic is removed from the mold by applying reverse pressure. It has wide applications in aeronautical manufacturing, automotive industries, boat building, computer industry, chocolate industry etc (www.formech.com).

Vacuum forming compared to other forming process possesses several advantages. The forming pressure required is very low enabling the tooling cost also to be low and since the pressure is low the mold used can be rapid prototyped thereby reducing the mold manufacturing time (Cohen, 2008).

Vacuum forming process

The thermoplastic sheet which is to be formed is inserted into the clamp area on the machine in its cold state. This thermoplastic sheet is then heated uniformly over the entire surface area and throughout its thickness to the desired temperature using a surface heater, which are generally infra-red elements mounted within an aluminium reflector plate. Once the plastic is heated and softens, it is then draped over the mold. During this time a vacuum is applied sucking the sheet onto the mold and to remove the air trapped between them. Once the plastic is formed to the required shape it is left to cool. To shorten the time for cooling a fan can be used. Releasing the part before cooling can cause deformation and part rejection. The cooled plastic along with the mold is removed from the vacuum system and by applying a reverse pressure the formed plastic is ejected from the mold. Figure 2.13 illustrates vacuum forming process.

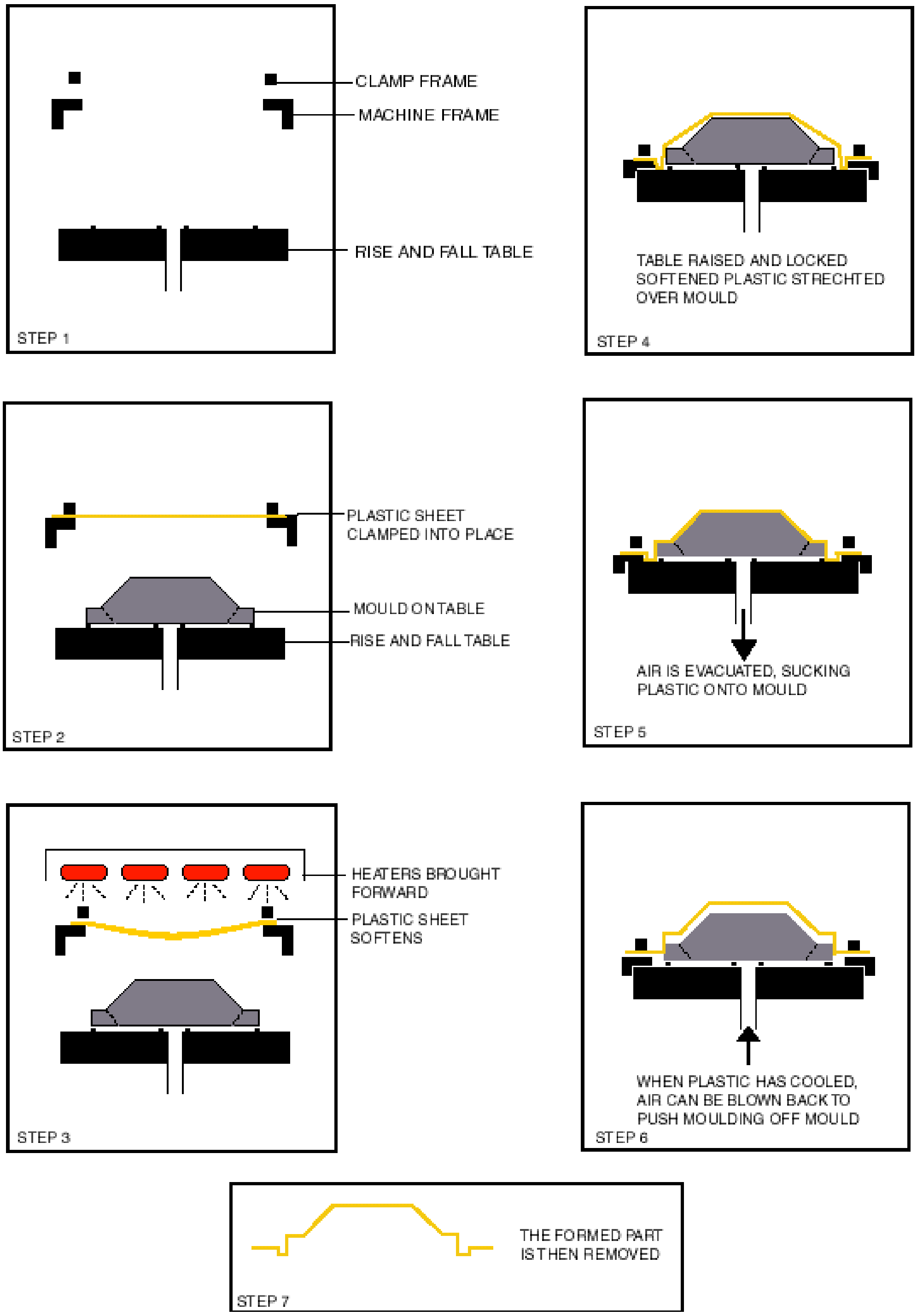

Figure 2.13 Vacuum forming process (source: www.formech.com)

Figure 2.14 shows the vacuum forming machine with the mold on the table and plastic sheet inserted on the frame, with a surface heater behind it.

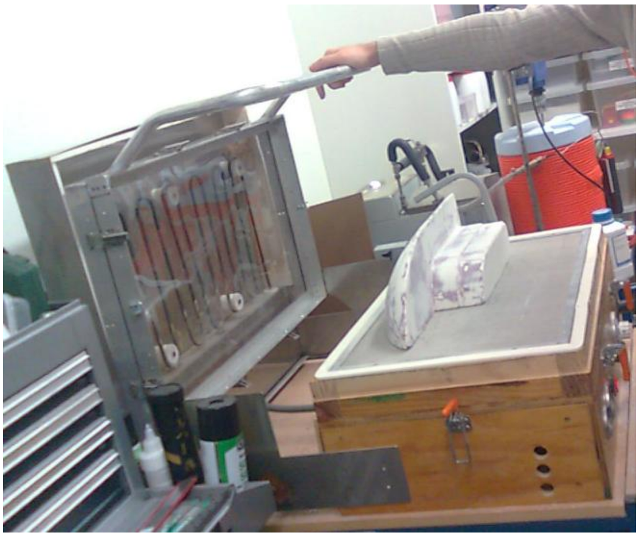

Figure 2.14 Vacuum forming machine

Before the formed hull is ready to use there are secondary operations required. The hull formed requires further edge cutting, which is cut using a knife leaving a small lip of 25mm on the outer edge. The purpose of lip is to glue the deck onto, also it adds to the strength of the hull.

Discussion

Through this project students get a good exposure to the soft skills and some hard skills required by an engineer, they learn about different manufacturing techniques, basic electric connections and at the same time the project manager learns how to manage a team which consists of members from different backgrounds. The skills learned during this project-based learning program give them a good exposure to real life problems faced by engineers which are usually not available from classroom teaching. But the drawback with the present method of the project is that though students use CAD packages to design the various parts of the boat, they do not apply the latest manufacturing methods available. They are not exposed to computer-aided manufacturing in any part of the project which is a major drawback for the mechanical engineering students involved in this project. The manufacturing of the parts are all produced using hand tools and power tools.

Through this paper students understand how things are made, learn craft skills and appreciate safety. This is a very labour intensive for students and an inaccurate way of making molds. However, it is cheaper as there is no labour cost involved and also students learn the process of making things by themselves which would not be possible if using modern manufacturing methodologies.

Conventional product development versus advanced product development

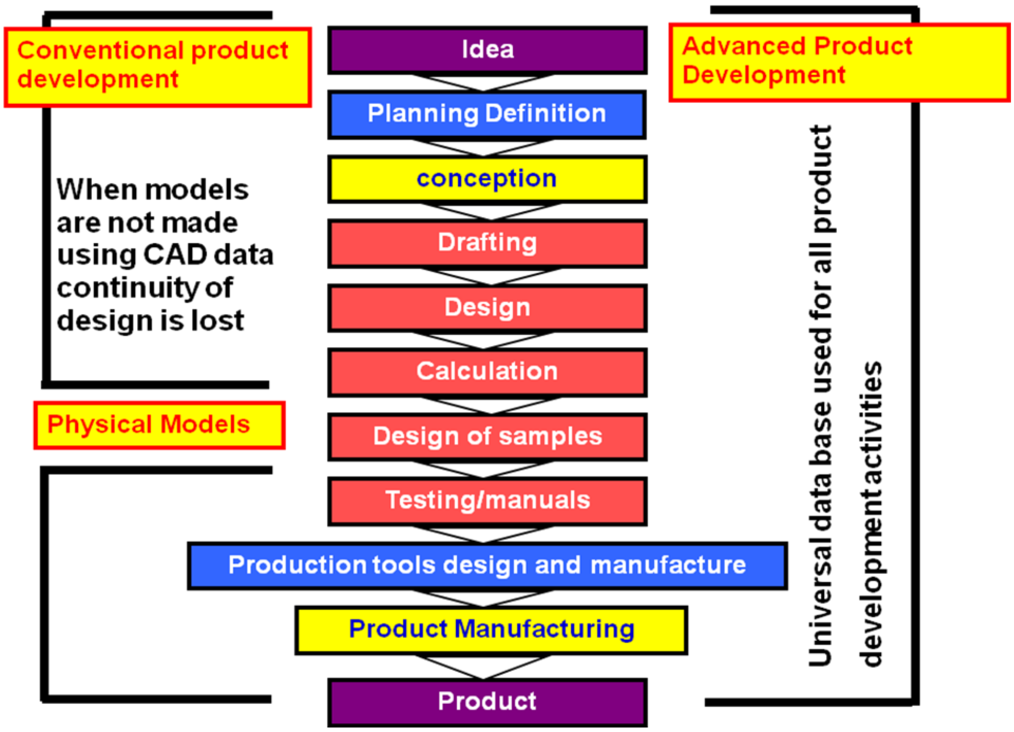

Figure 2.15 Comparison between conventional product development and advanced product development (source: ENME480)

Figure 2.15 shows the difference between conventional product development and advanced product development. Through conventional methods the students learn handcrafting skills but when models are not made directly from CAD, data continuity is lost, whereas in advanced product development the final product is accurate to the CAD design. This loss of data can be avoided by implementing the advanced product development methods. The mold for the hull can be built for example from MDF using a CNC milling machine directly from the CAD design. In addition many of the boat components are made from plastic sheet that is hand cut. Advanced methods would use for example a 2D laser cutter to achieve the profile direct from CAD model. An example of this would be the rudder as it can easily be cut by 2D laser cutter.

Chapter 3 Review of Boat Design

As already mentioned in the introduction, the model boats made by undergraduate engineering students are rather primitive in design. This literature review investigates various speed boat hull shapes and their features. The objective is to determine whether researching existing literature on hull design would provide information about optimal hulls, applicable to the model boat project. This review aimed to find out key design features for a fast boat that students could not do due to lack of time. This review could be used as teaching material for the students to help them design ‘optimal’ boats.

3.1 Boat Terminology

Figure 3.1 shows some commonly used nautical terms by boat designers. It is important to have an idea about these terms before going into detail.

Figure 3.1 Boat Terminologies (Sweet, 2007)

Definitions:-

Bow: The front or the forward part of the boat is called bow (Palmer, 2005).

Stern: The rear or aft part of boat is known as stern (Palmer, 2005).

Transom: The flat end of the hull is called transom (Palmer, 2005).

Beam: It is the width at the boat's widest part, also called the breadth (Palmer, 2005).

Deck: It is the permanent covering over the hull (Palmer, 2005).

Quarter: The area between beam to stern is quarter (Sweet, 2007).

3.2 Hull Measurements

Figure 3.2 Hull Measurements (Sweet, 2007)

Figure 3.2 shows the various hull measurements.

Length Overall (LOA) is the overall length of the boat, the distance between the foremost point on the bow to the aft point on the stern. Its primary importance is to know the amount of space required to tie up the boat along jetties (Clark & Mariner, 2002).

Waterline length (LWL) is the length of the boat at water surface (Sweet, 2007).

Freeboard is the height of boat's deck edge from the waterline (Figure 3.3). Freeboard is generally maximum at the bow and minimum at mid-ship region (Clark & Mariner, 2002), but varies with the speed of boat (Marshall, 2002).

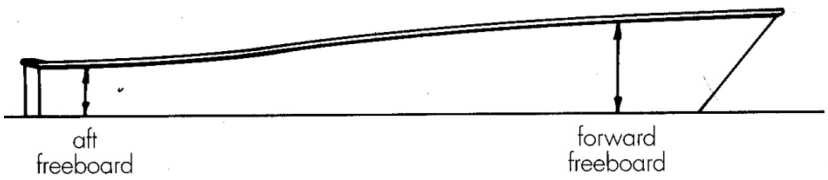

Figure 3.3 Freeboard (Marshall, 2002)

Draft is the depth of hull region beneath the waterline (Clark & Mariner, 2002).

Trim is the difference between forward and aft drafts. Draft at the stern is more than at bow to ensure the propellers are well immersed in water (Clark & Mariner, 2002)

3.3 Boat Locations or Directions

Figure 3.4 Directions on the boat (Sweet, 2007)

Figure 3.4 shows the locations on the boat. Forward and aft indicate the directions or locations on the boat, while ahead and astern indicates the directions or locations beyond the boat. The left side of boat is called port and the right side is starboard (Sweet, 2007).

3.4 Features of Speedboat Hull

3.4.1 Chine

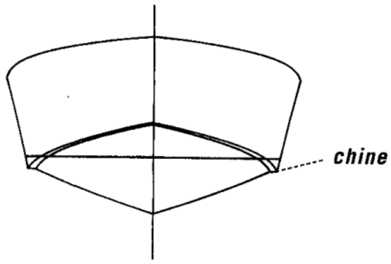

Figure 3.5 Boat Chine (Pike, 2004)

A chine refers to an angle on either side of the boat running from the bow to stern, where the hull bottom meets the sides. They are visible at the bow and disappear under water towards the middle of the boat as shown in Figure 3.5 (Marshall, 2002)

Chine's are of three types

- Hard (angular)
- Soft (rounded)
- Reverse

Hard Chine (angular)

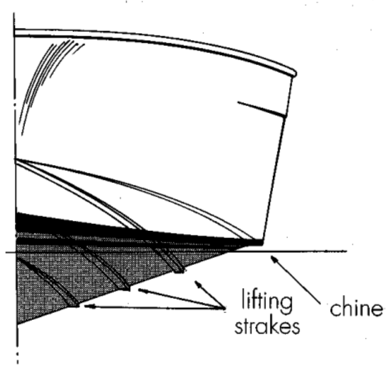

Figure 3.6 Hard Chine (Marshall, 2002)

The purpose of hard chine is to throw away the water spray to the sides, to prevent it from reaching the hull sides to increase the drag. Hard chines have a sharp angle.

They are found on semi-planing and planing boats (Sweet, 2007). Figure 3.6 shows a hard chine boat.

Soft Chine (rounded)

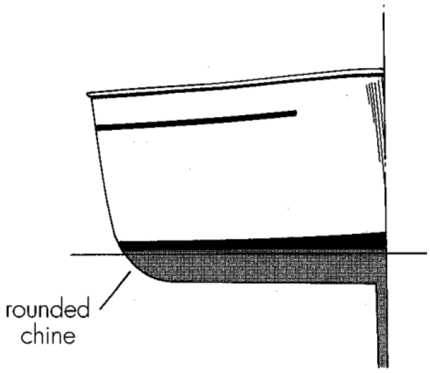

Figure 3.7 Soft Chine (Marshall, 2002)

Soft chines do not have a sharp angle but a sharp turn as shown in figure 3.7. They provide a smoother ride compared to hard chine but their top speed is less than a hard chine (Sweet, 2007).

Reverse Chine

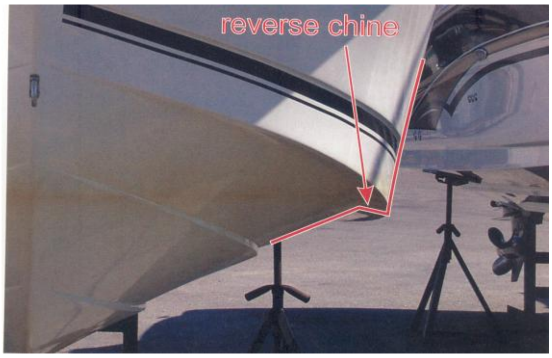

Figure 3.8 Reverse Chine (Sweet, 2007)

Reverse chine have a downward turn (Figure 3.8) towards the water surface, when viewed in section. They are found in Boston Whaler, to deflect the water thrown out by the central hull (Sweet, 2007).

3.4.2 Deadrise

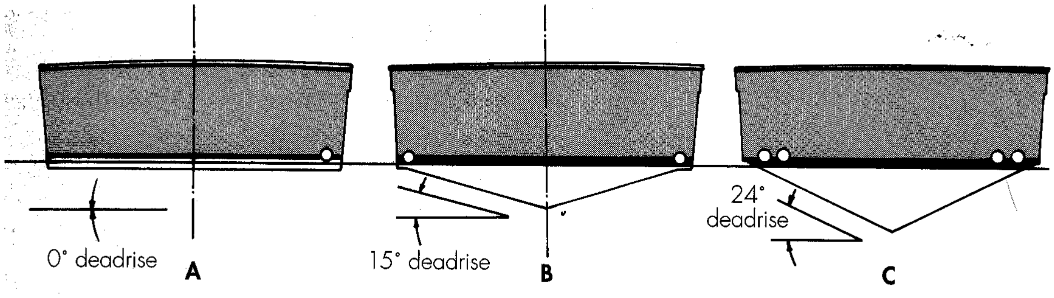

Figure 3.9 Various Deadrise angles (Marshall, 2002)

Deadrise is the angle made by the hull bottom with the horizontal plane when viewed from ahead or astern. The right angle of deadrise provides a boat directional stability, a softer ride, and reduces wetted surface drag as the boat rises onto the plane. If the angle stays the same from the middle of the boat to transom it is said to be a constant deadrise and variable if it changes from a deep angle at the mid-section to a shallow angle at the transom. Constant deadrise are usually found on deep-V hulls (Marshall, 2002). Figure 3.9 shows various deadrise angles.

3.4.3 Running Strakes (Lifting Strakes)

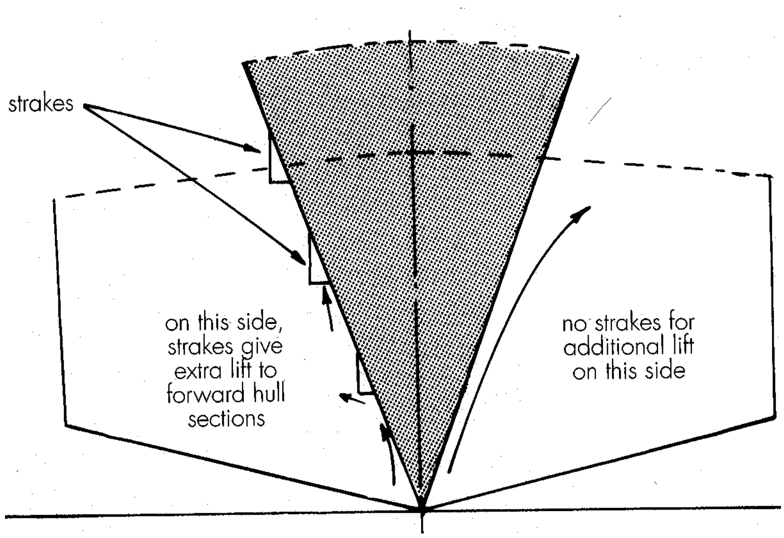

Figure 3.10 Running Strakes on a V-Hull (Marshall, 2002)

Running Strakes are strips, triangular in cross section with bottom face parallel to the water surface as shown in Figure 3.10. They peel away water from the hull around the waterline to reduce the friction between hull and water; they also provide additional lift for high speed hulls (Pike, 2004). An additional drag is also created by these strakes, to avoid that they usually end about one-half to two-thirds of the way aft. At displacement mode strakes are fully immersed in water, gradually as speed increases they provide lift and begin to emerge out of water with the bow. As speed increases and the boat gets onto the plane, all the strakes rise clear of water eliminating their lift and also the drag caused by them. When in plane the hull rides on the aft portion of its bottom with no strakes in the water (Marshall, 2002).

3.5 Boat Stability

It is the ability of a boat to maintain equilibrium, i.e. to stay in or return to its upright position after it has suffered a small disturbance (Rawson, 2001). The stability of a boat depends upon its center of gravity and center of buoyancy (Sweet, 2007).

3.5.1 Center of Gravity

The center of gravity is an imaginary point within the hull where the entire weight of the boat is considered to be focused (Figure 3.11). The force of center of gravity acts downwards, pushing the weight of the boat into the water. Center of gravity is relatively at a fixed location however, the position can be changed by redistributing the weight to different locations. The lower the center of gravity of a boat the more stable it is. (Sweet, 2007).

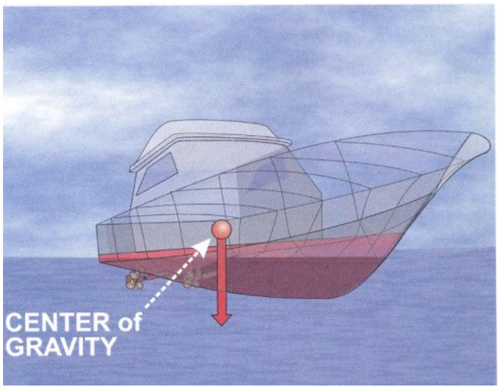

Figure 3.11 Centre of gravity (Sweet, 2007)

3.5.2 Center of Buoyancy

Buoyancy is the upward force acting on the hull when it is displaced in water. This force is considered to be acting on a single point which is known as center of buoyancy, it acts against the center of gravity. While the location of the center of gravity is relatively at a fixed position, the location of the center of buoyancy keeps moving (Sweet, 2007).

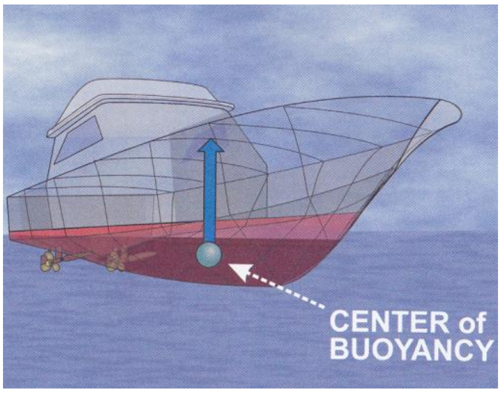

Figure: 3.12 Center of buoyancy (Sweet, 2007)

3.6 Hull Types

There are basically 3 types of hull:-

- Displacement hull
- Semi-displacement hull
- Planing hull

Displacement hull

A displacement hull has a rated speed for a certain power. Increasing the power beyond this value will have minimal impact on speed. As the name signifies, it always displaces the same amount of water and never gets onto plane. The maximum speed at which it can go depends on its waterline length. However in spite of these drawbacks, they have much to offer: comfort, seaworthiness, range, load-carrying ability and fuel economy. Hence they are used to carry cargo, heavy loads, and oil. Oil tankers, tugs and many super yachts have displacement hulls (Marshall, 2002). Figure 3.13 shows a displacement hull.

Figure 3.13 A 43 foot displacement hull (Sweet, 2007)

The maximum speed a displacement hull can go is approximately 1.34 times the square root of the waterline length (LWL) (Sweet, 2007).

$1.34 \times \sqrt{(LWL)} = \text{hull speed}$ (LWL is in feet)

For example, for a 20 footer the hull speed would be $1.34 \times \sqrt{(20)} = 6$ knots. If the boat is longer, the faster the speed will be, for a 500 foot long carrier, the speed is $1.34 \times \sqrt{(500)} = 30$ knots, however with a very powerful engine the hull speed can be pushed up to 1.5 times the square root of waterline length but there will be a dramatic increase in fuel consumption for this narrow increase in speed (Sweet, 2007).

Semi-displacement Hull

A semi-displacement hull can go faster than a displacement hull, they have a limited amount of dynamic lift which helps them rise on their bow waves and achieve higher speeds than displacement hulls. Semi-displacement hulls have a speed-to-length ratio of 2 to 3.5 (Sweet, 2007). Figure 3.14 shows a semi-displacement hull.

Figure 3.14: A semi-displacement hull (Sweet, 2007)

Planing Hulls

A boat is said to be planing when it is riding on its own bow wave (Sweet, 2007). Initially at low speed, the boat displaces water equivalent to its own weight, as speed increases gradually, the boat lifts up of the water using hydrodynamic lift to reduce the wet surface area and reduces the drag. As the hull reaches an appropriate angle of incidence to the water flow, trimming up by the bow to generate lift, the boats starts to plane. When this hydrodynamic lift generated is equivalent to the boat’s weight, the hull rises from the water and starts to plane on its own wave (Marshall, 2002). Figure 3.15 shows a planing hull.

Figure 3.15 A high speed planing hull (Sweet, 2007)

For a boat to reach its planing speed requires considerable engine power, the boat has to be light in weight and have a hull with dynamic lift. To convert the motion in water to vertical lift the hull has to have specific design characteristics, the more efficient these lifting characteristics are the lower the speed required reaching planing. Once the boat reaches onto the plane the efficiency increases and less engine power is required to stay on plane because there is now less wet surface area, so less resistance (Sweet, 2007)

3.7 Hull Shapes for Speed boats

Flat-bottomed hull

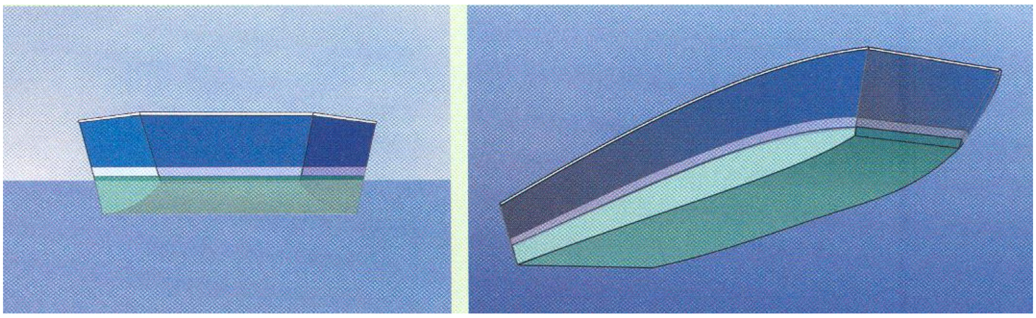

Figure: 3.16 Flat-bottomed hull (Sweet, 2007)

These boats are basically used for fishing and hunting as they are quite stable initially. They are designed for small lakes and slow rivers as they do not handle well in rough water. Flat-bottomed hulls are not more than 20 feet long (Sweet, 2007). Figure 3.16 shows a flat-bottomed hull.

Deep-V hulls

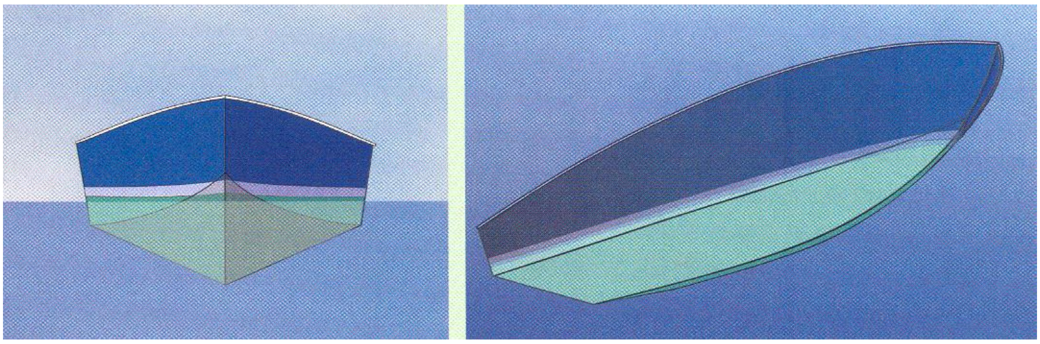

Figure: 3.17 Deep-V hull (Sweet, 2007)

They have a deadrise ranging from 22 to 28 degrees at the transom (Pike, 2004).These are very popular boats for several reasons. The deep-V shape cuts through the water and provides a cushioning effect but can become unstable at higher speeds. The sharper the V, the more power required to get onto the plane (Sweet, 2007). Figure 3.17 shows a deep-V hull.

Shallow-V hulls

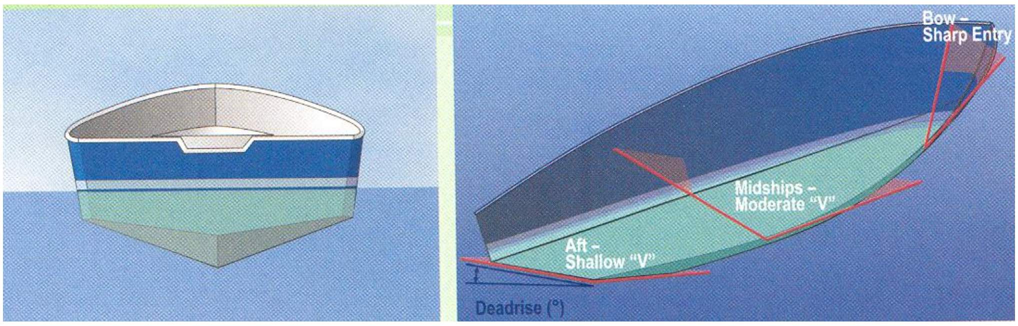

Figure 3.18 Shallow-V hull (Sweet, 2007)

They have a very low deadrise angle, pound very heavily in waves giving an uncomfortable ride (Sweet, 2007). Figure 3.18 shows a shallow-V hull.

Catamaran

These are multi hulls joined together at the deck as shown in Figure 3.19. They give the speed and efficiency of narrow hulls along with the stability of wider beam hull. Catamarans can either be displacement or planing (Sweet, 2007).

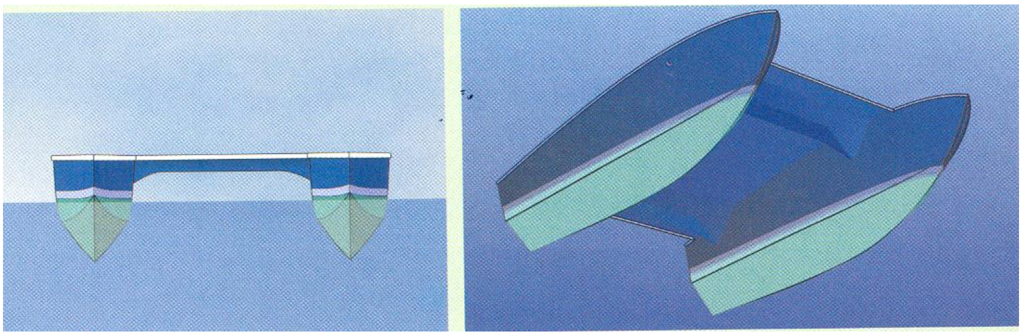

Figure: 3.19 Catamaran (Sweet, 2007)

Stepped Hull

They are high speed planing hull with steps across the hull bottom (Figure 3.20). These steps reduce the hydrodynamic resistance at high speed, thus make it more efficient compared to an equivalent mono hull (Savitsky & Morabito, 2009).

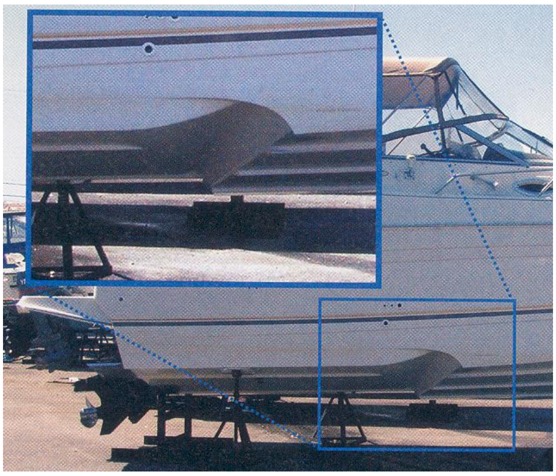

Figure 3.20 Stepped hull (Sweet, 2007)

3.8 Wet Surface

Wet surface is the amount of hull surface in contact with water. When in displacement mode a boat displaces water equivalent to its weight, at this point the wet surface area is more (Figure 3.21), so is the amount of hull friction (Sweet, 2007).

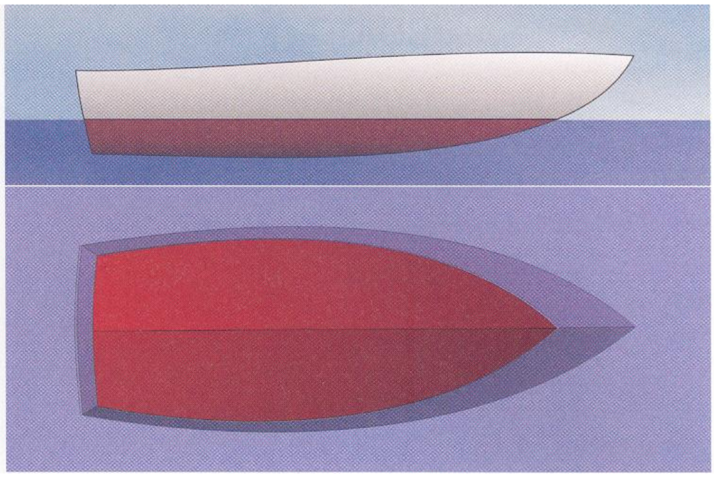

Figure 3.21 A Planing boat in displacement mode (Sweet, 2007)

A planing hull, when speed increases gradually lift up from its displacement mode, reducing its wet surface area and thereby reducing its hull drag as shown in Figure 3.22.

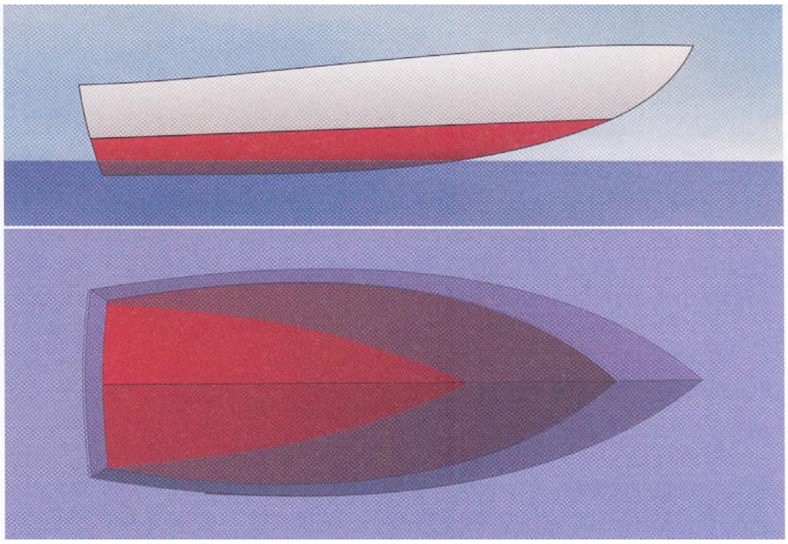

Figure 3.22 Planing hull lifting up reducing its wet surface area (Sweet, 2007)

If the wet surface area is less, the hull friction is also less, which means higher speeds with less power. When in fully planing mode the hull has least wet surface area as shown in Figure 3.23.

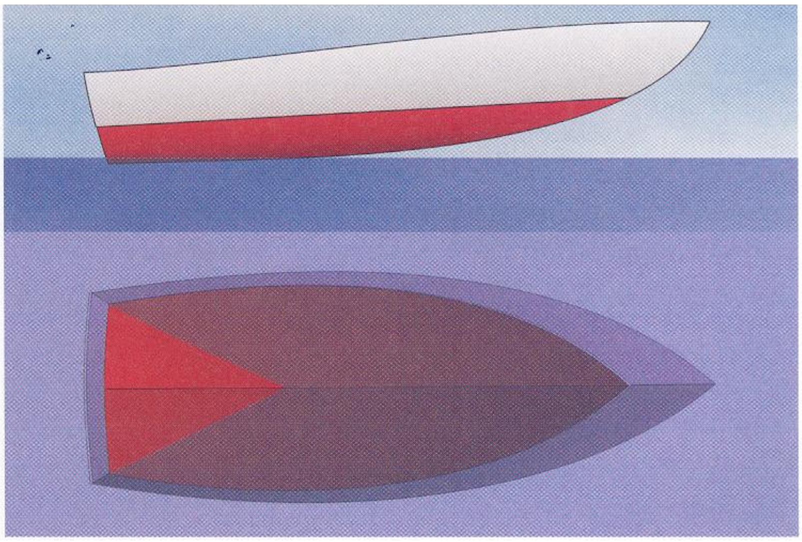

Figure 3.23 Boat in planing mode with minimum wet surface area (Sweet, 2007)

Wet Surface area of a Stepped Hull

Figure 3.24 shows the wet surface area of a stepped hull while the boat is planing. The step located somewhat aft of the mid-hull separates the water-flow from the bottom, thus reducing the wet surface area (Savitsky & Morabito, 2009).

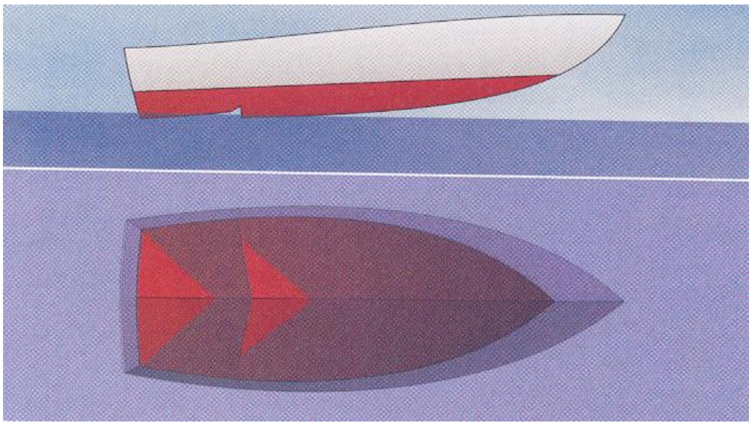

Figure 3.24 Wet Surface of a stepped hull when planing (Sweet, 2007)

3.9 Different stages of a planing boat

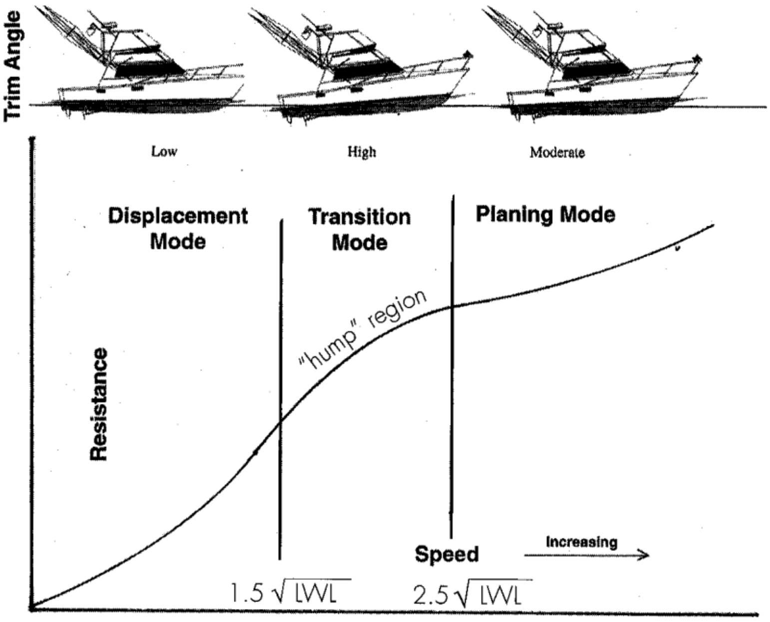

Figure 3.25 Resistance versus speed graph of a planing boat (Marshall, 2002)

Figure 3.25 shows the resistance versus speed graph of a planing boat. As previously mentioned, the maximum speed a boat can go in displacement mode is 1.34 times the square root of its waterline length, by applying more power it can be pushed up to 1.5 times but most displacement hulls are incapable of speeds higher than that. This is because at this speed the wave created by the hull stretches from the bow to stern and the displacement hull cannot climb its bow wave which is too steep. Applying more power at this stage can only cause the stern to squat and boat to strain. Above this speed lies the hump region, a transition mode from displacement to planing mode. A planing hull when accelerated jumps from displacement mode to transition mode by climbing the bow wave created. When the speed reaches 2.5 to 5 times the square root of waterline length the boat is out of the hump region. At this stage less power is required to stay on plane as hydrodynamic lift supports much of boats weight, wet surface area is also less (Marshall, 2002).

3.10 Propellers

The propeller is the output end of the drive system, which transmits engine power by converting the rotational motion to thrust. A propeller's efficiency depends upon how much power is converted to thrust (Marshall, 2002). Figure 3.26 shows some propellers used in model boats.

Figure 3.26 Model boat Propellers (source ampba.asn.au)

Parts of the Propeller

Figure 3.27 shows the different parts of a propeller, these are expanded in the following sections.

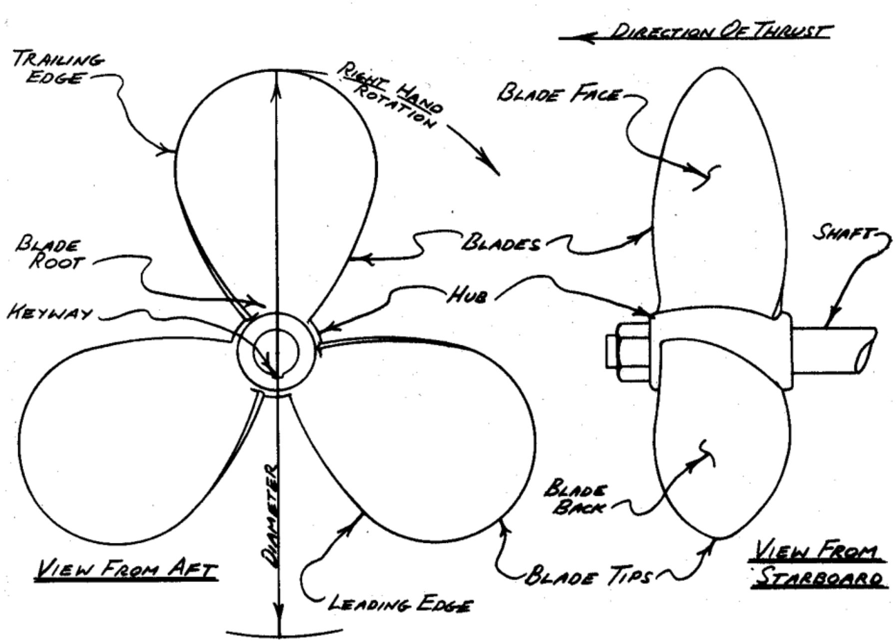

Figure 3.27 Propeller Anatomy (Gerr, 2001)

Hub (or boss): The solid cylinder at the center of a propeller to which the blades are attached. The hub is bored to accommodate propeller shaft and is usually not less than 14 percent of the diameter in order to have sufficient strength (Gerr, 2001).

Keyway: The long rectangular slot on the hub to fit in the shaft key, to avoid rotational slip of the shaft. The torque from shaft is transmitted to propeller through this key (Gerr, 2001).

Blades: Propeller blades are twisted fins or foils attached to the hub. The action of propeller blades pushes the boat through the water (Gerr, 2001).

Blade Face and Blade Back: The high pressure side of the blade which pushes water when the boat is moving forward is blade face and the low pressure side is blade back (Gerr, 2001).

Blade Root and Blade Tip: Blade root is the point on the hub where the blades are attached. Blade tip is the extreme most tip on the blade far from the hub center (Gerr, 2001).

Leading and Trailing Edges: The edge of the blade that cuts through the water is the leading edge and the blade edge from where the water moves away is the trailing edge (Gerr, 2001).

Propeller Rotation

A propeller that rotates in the clockwise direction while propelling the boat forward is known as a right-handed propeller, while a propeller that rotates in the anti-clockwise direction when propelling the boat forward is a left-handed propeller. When viewed from astern the leading edge of propeller will always be farther away than the trailing edge. If the leading edges are towards the right side when viewed from astern it is a right handed propeller and if the leading edge is towards the left it is a left-handed propeller. A propeller hand can never be changed i.e. a right-handed propeller cannot be changed to left-handed by turning it backwards or vice-versa (Gerr, 2001).

Prop Walk

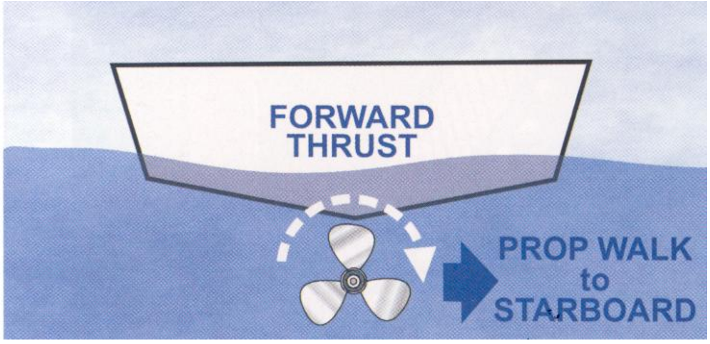

Figure 3.28 Prop walk to starboard (Sweet, 2007)

When a boat is propelled, the propeller not only produces forward thrust but also a small amount of side thrust, called prop walk (Sweet, 2007). This side thrust is caused because the water below the propeller is denser than water above the propeller, which makes the lower blades more effective and pushes the stern sideways in the direction of rotation of propeller. When propelling forward, a right handed propeller produces thrust towards the right, pushing the stern to the right as shown in Figure 3.28 and a left hand propeller produces thrust towards the left side that pushes stern to left (Gerr, 2001)

Twin Screw Rotation.

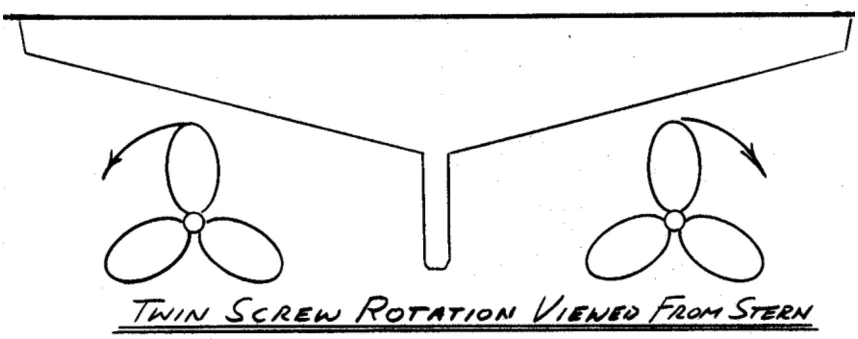

Figure 3.29 Twin screw rotation (Gerr, 2001)

For twin screw boats, the propellers should be out-turning as shown in the Figure 3.29. The starboard propeller should be right-handed and the port propeller should be left-handed. Since the two propellers operate in opposite direction, the side thrust gets cancelled. If one of the engines is propelling forward and the other reverse, increases in the side thrust can actually be used for turning. Twin screw boats with same hand propellers can cause serious handling issues (Gerr, 2001).

Propeller Characteristics

The three most significant factors affecting the propeller efficiency are diameter, revolutions per minute (rpm) and pitch.

Diameter

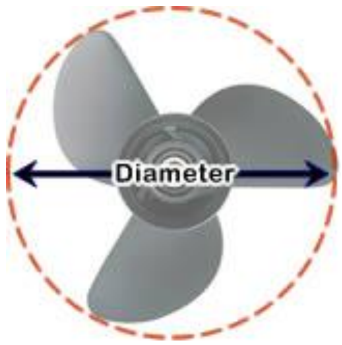

Figure 3.30 Propeller Diameter (source www.bblades.com)

The diameter of a propeller is the distance across the circle the propeller makes when rotating as shown in Figure 3.30. It is the most critical factor in determining the amount of power a propeller absorbs and transmits, also the most important single factor in determining the amount of thrust delivered. A small increase in diameter can have a dramatic increase in thrust and torque load on an engine, so for a larger diameter, the shaft speed must be slow. In most of the cases the larger the diameter the greater the efficiency but for high speed vessels of 35 knots or more the extra wetted surface of large-diameter shafts & bearings adds to excessive drag (Gerr, 2001).

Revolutions per Minute (rpm)

The number of rotations made by the propeller in a single minute is the propeller rpm, also called shaft rpm since they both rotate at the same speed. Higher rpm is beneficial for high speed vessels where it is important to keep the propeller size and its supporting structure small to reduce the appendage drag (Gerr, 2001).

Pitch

The theoretical linear distance travelled by the propeller in a single rotation is called pitch (Figure 3.31). If, for every complete rotation a propeller moves forward 10 mm, then the propeller pitch is 10mm. Since the propeller is attached to the motor shaft and that to the hull, for every rotation of the propeller, the propeller pushes the hull forward but the distance travelled by the hull is less than the theoretical pitch value, this difference between the theoretical pitch and the actual distance travelled is called slip (Figure 3.32) (Gerr, 2001). The pitch is high when the blade is flat (Sweet, 2007).

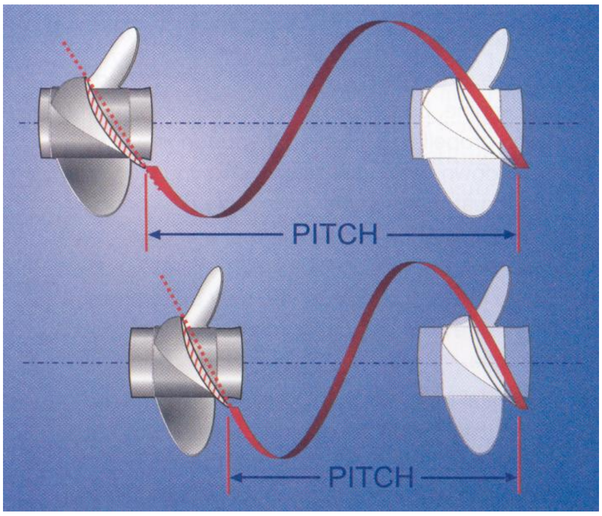

Figure 3.31 Propeller pitch (Sweet 2007)

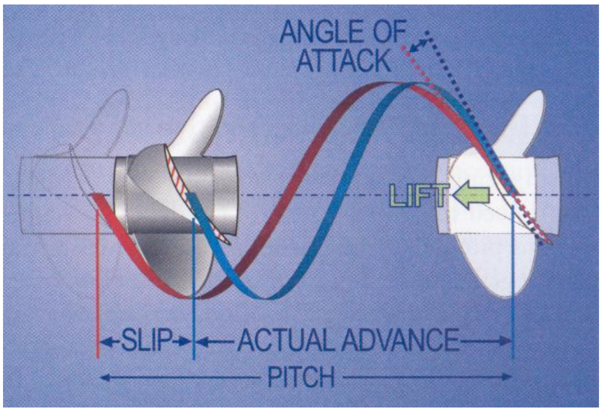

Figure 3.32 Propeller Slip (Sweet, 2007)

By pushing the water astern, the torque from propeller shaft is converted to thrust. F = ma (Newton's Second Law), the thrust or force is directly proportional to the mass of water moved astern times the acceleration of that mass (Gerr, 2001).

Characteristics of blades

Number of blades

High speed powerboats use two blade propellers to reduce drag, but for effective thrust such propellers require very large diameters to get the required blade area. Hence three bladed propellers have proven to be the best compromise between balance, blade area and efficiency. Multiple blade propellers i.e. 4 blade or 5 blade propellers have the advantage of having more total blade area for the same or less diameter. However, they are often not as efficient as three blade propellers as the closer blades create additional turbulence (Gerr, 2001).

Blade area

It is the surface area of individual blades on a propeller. The complex shape of a propeller blade makes its surface area calculation difficult (Gerr, 2001).

Rake

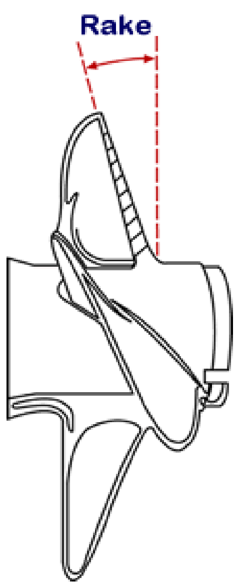

Figure 3.33 Propeller Rake (www.bblades.com)

When viewed from the side, propeller blades lean or slope either forward or aft, this is known as rake (Figure 3.33). When the blades slope aft it is said to have positive rake and when they lean forward its called negative rake. The purpose of positive rake is to increase the effective diameter because raked blades have more length and more area than vertical blades of the same diameter. High-speed vessels and highly loaded vessels usually employ negative rakes, to help strengthen the blades (Gerr, 2001).

Cavitation

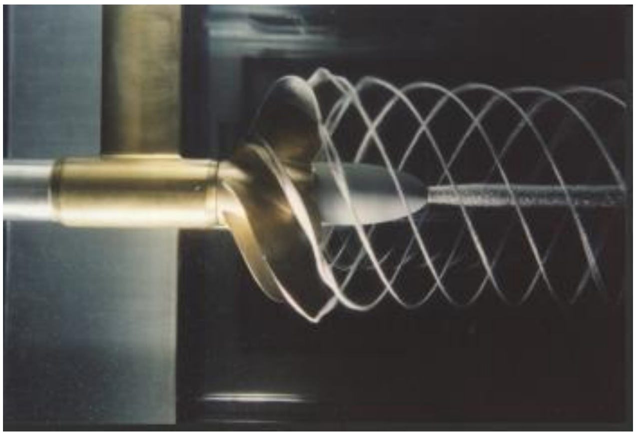

Figure 3.34 Propeller Cavitation (source www.amc.edu.au)

A low pressure area is developed on the back surface of the blade when rotating at high speed. This low pressure area spreads across the blade, leading to the formation of tiny bubbles of water vapour during excessive speed, causing loss of thrust. This phenomenon is known as cavitation (Figure 3.34). The propeller loses its grip on the water and rotates inefficiently during cavitation (Marshall, 2002). Severe cavitation may cause wearing of blades, reduction in propulsive power and vibration that can bend the blades (Dokkum, 2003).

Ventilation

When the propeller blade is turning near the water surface, air is sucked down into the spinning blade, this is known as ventilation (Marshall, 2002) as shown in Figure 3.35. Ventilation can lead to loss of thrust and also cause vibration. Surface propellers are specifically designed to entrain air but for others propellers ventilation must be avoided. Ventilation can be prevented by placing the propeller deeper from the water surface or by reducing the propeller diameter (Gerr, 2001).

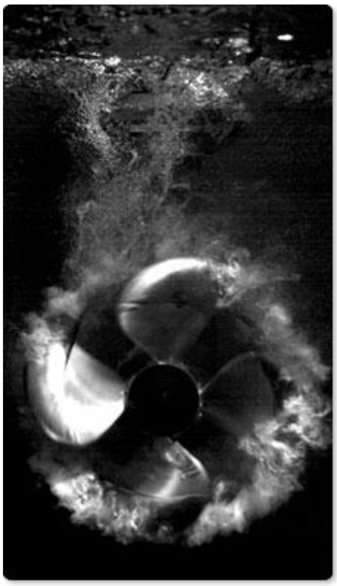

Figure 3.35 Propeller Ventilation (Source www.ntnu.no)

Special Types of Propellers

Ducted Propeller

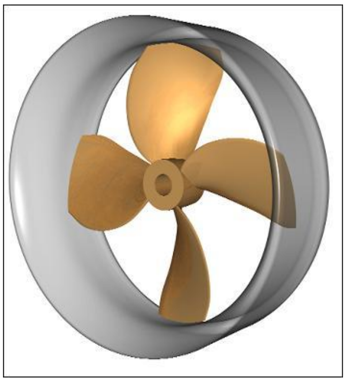

Figure 3.36 Ducted Propeller (Source www.swirljet.net)

Ducted Propellers have square-tipped blades, surrounded by a closely fitted shroud with very little clearance between blade tips and the inside of the shroud as shown in Figure 3.36. The blades are very similar to standard elliptical blades with the outer 20 percent chopped off at right angles. The thrust generated by a ducted propeller is more than the thrust generated by a standard propeller with the same engine, but its effect is significant only on low speed vessels of 9 to 10 knots and with heavily loaded blades (Gerr, 2001).

Surface Propeller

Figure 3.37 Surface Propeller (Source www.boatdesign.net)

Surface propellers operate half in and half out of water (Figure 3.37), i.e. each blade on every complete rotation cleaves through water and comes out to atmospheric air, and they are specifically designed for this purpose. Since surface propellers are exposed to air, they get aerated and this prevents cavitation. These propellers are employed on high speed boats that operate regularly over 35 knots (Gerr, 2001).

When planing, water reaches only up to the hub of the propeller so only the bottom blades are in water. The propellers used have thicker blade sections, sharp leading edges and thick trailing edge to improve performance and reliability. To avoid unwanted vibration at high speed odd numbers of blades are used in surface propellers (Pike, 2004).

Discussion

It is clear from this review that over a century of propeller research has lead to well understood and optimised designs for a wide range of application. It is not considered appropriate for ENGG180 students to undertake extreme research into propeller design, as they are provided with standard propellers. The lab experiments in ENGG180 are probably enough for students to understand how they perform. However, it might be useful to give them a fact sheet, similar to this review so they understand better how the work.

3.11 Engine types

The heart of a boat is its engine that is connected to a propulsive system comprising a shaft and propeller. The engine produces torque and rotates the propeller, which produces thrust to move the boat forward or backward (Palmer, 2005). Propulsive systems are of different types:

Inboard Drive

In an inboard drive system, the engine, gears and most of the shaft is inside the hull as shown in Figure 3.38 (Palmer, 2005). Since the propeller is outside the hull, the propeller shaft is routed through the hull in a sealing device to connect the propeller. For the shaft to go through the hull, both engine and shaft are angled down a few degrees, but as the slope increases the efficiency decreases and reduces the thrust generated. These slopes are not generally more than 15 degrees (Marshall, 2002).

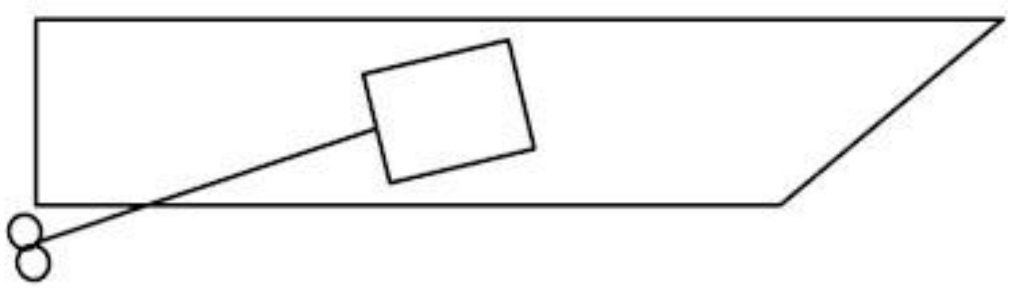

Figure 3.38 Inboard engine (Palmer, 2005)

Outboard drive

In an outboard drive, the entire propulsive system is bolted to the transom of the boat outside the hull. An outboard engine can be turned to control a boat's direction hence they can avoid having a rudder. Since the whole propulsion unit is outside the hull it is easy to install and handle. Another advantage is that the engine can be positioned so the propeller is parallel with the water surface for maximum thrust (Marshall, 2002).

Sterndrive

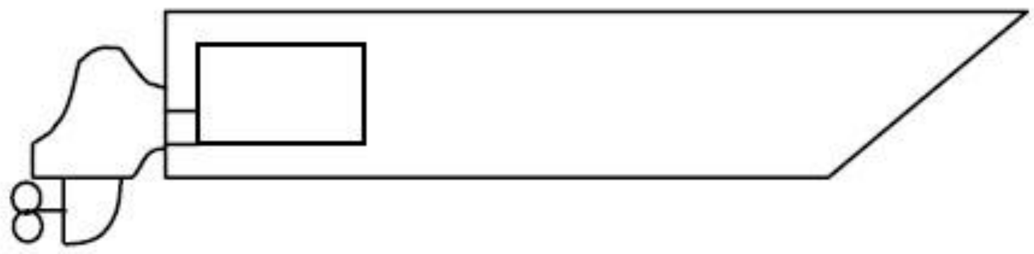

Figure 3.39 Sterndrive (Palmer, 2005)

A hybrid of inboard and outboard drive is known as sterndrive, also called as inboard-outboards. In a sterndrive the engine is fixed to the transom from inside the hull. The transmission gear from the engine goes through the transom to connect to the propeller shaft. Sterndrives do not require a rudder hence installation is slightly easier. When not in use, the propeller can be raised almost out of water (Marshall, 2002). Figure 3.39 shows a stern drive.

Jet Drive

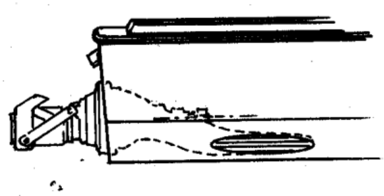

Figure 3.40 Jet Drive (Pike, 2004)

A jet drive sucks water into a tunnel in the hull and is accelerated by a propeller. This water is sent out through a nozzle astern at high speed to propel the boat. The nozzle is directionally controllable so a jet drive too avoids the need for a rudder. The advantage of a jet drive is that since there is no propeller sticking outside the hull, they are safe to be used in shallow water and can also be safely used around people in water. In spite of these advantages they do have some disadvantages like: the efficiency of a jet drive is 30 percent less than that of a propeller driven outboard; the water intake grill has to be kept clear of weeds, plastics or anything that obstructs the intake of water else it would lead to loss of efficiency (Marshall, 2002). Figure 3.40 shows a jet drive boat.

3.12 Steering

There are two different types of steering for fast boats.

- Passive steering
- Dynamic steering

Passive Steering

In passive steering rudders are used, they deflect the water to sides creating a sideways thrust at the stern to turn the boat (Pike, 2004).

Rudders

A rudder is a vertical plate mounted behind the propeller to control the boat's direction. They can be turned to port side or starboard side as required. When the rudder is turned towards any one side, the water flow from the propeller gets diverted to that particular direction, pushing the stern to the opposite side causing the boat to turn (Sweet, 2007).

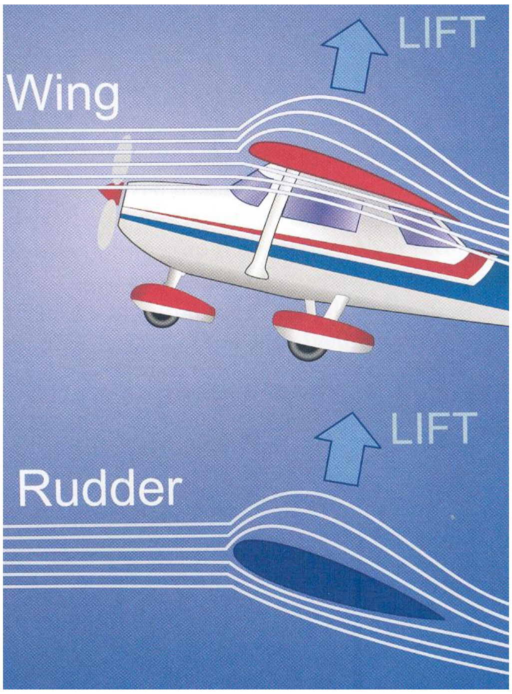

Figure 3.41 Lift generated by rudder (Sweet, 2007)

Rudders are similar to airfoils; they generate lift in water like airplane wings generate lift in air as shown in Figure 3.41.The lift generated by the flow of water on the outer side provides more turning force than the push generated by the flow of water on the inner side. Rudders can be made flat but to increase this lifting force they are made curved in cross section. The size of the rudder and the speed of water passing over it determine the turning force. The greater the speed of water flow over the rudder, the more responsive the boat will be and the boat would not make a turn if there is no water flow (Sweet, 2007).

In slow speed boats for maximum steering effect the rudder size has to be as large as possible but at high speeds such rudders adds to resistance and are too sensitive. For high speed boats smaller size rudders are preferred in order to keep the resistance low and also because speed provides effective steering. Twin screw boats use two rudders, one behind each propeller (Pike, 2004).

Dynamic Steering

In dynamic steering the propeller shaft is moved from side to side to turn the boat. Outboard, stern drive and water jet propulsive systems use dynamic steering but in water jet the nozzle is moved. The dynamic steering has got a stronger effect compared to a rudder system; they have half the turning circle compared to that of the same boat employing a rudder system (Pike, 2004).

3.13 Steering with Twin Drives

In a twin drive boat when the boat is moving in a forward direction with both the engines at different speed, the boat turns i.e. if the port engine is driven at a higher speed than starboard engine the boat will turn to the starboard side and vice-versa. If a sharper turn is required then the boat can be propelled by a single engine.

In boats with closely placed propellers, turning the boat by increasing the speed of one propeller does not provide enough side thrust for turning, in such cases it is preferred to run one engine in forward gear and the other in reverse gear as shown in Figure 3.42.

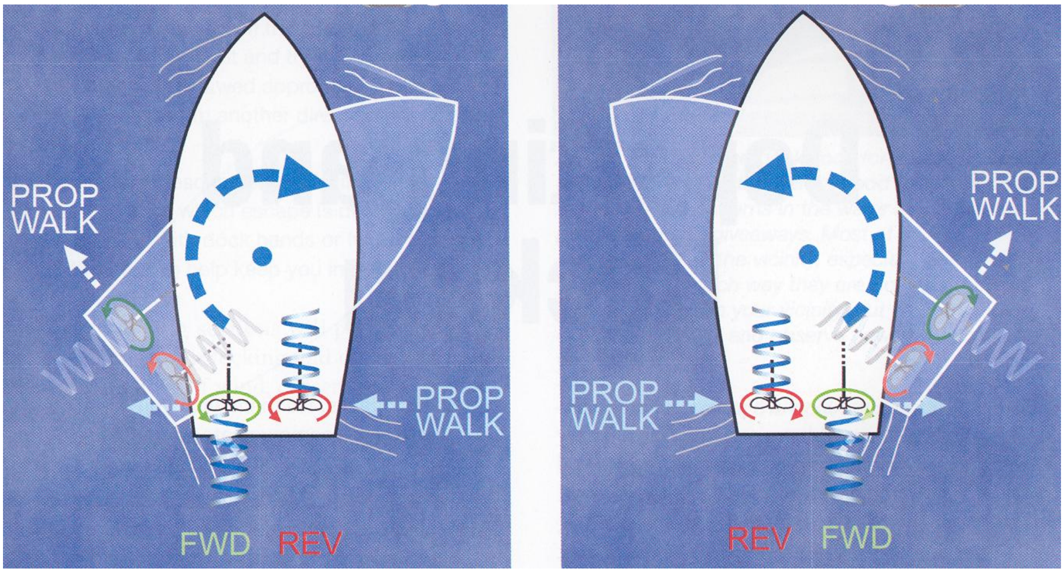

Figure 3.42 Twin drive boat steering (Sweet, 2007)

3.14 Boat Resistance

To propel a boat it first needs to overcome the resistance force acting against its propulsion. This resistance of a boat depends upon its velocity, displacement and hull form (Minami & Yamachika, 2004). The various types of resistance generated are discussed below.

- Frictional Resistance
- Residual Resistance
- Appendage Resistance
- Air Resistance

Frictional Resistance

Frictional resistance is a function of the wetted area of the hull, density of the fluid, velocity of the fluid over the surface and surface roughness. For a rough surface, the skin friction increases with the square of the velocity but for a smooth surface the increase is at a power less than 2, so it is very important to maintain the hull surface as smooth as possible (Gillmer & Johnson, 1982).

Residual Resistance

Residual resistance is made up of wave resistance and eddy resistance.

Wave Resistance

A boat, while moving through an undisturbed water surface, produces a very particular pattern of waves at the bow and at the stern. Bow waves are more significant because they are larger, predominant and carry along the boat's hull affecting the pressure distribution in the water where boat is acting. When the boat moves forward it produces a characteristic pattern of waves in series of diagonal or oblique crests as shown in Figure 3.43 (Gillmer & Johnson, 1982).

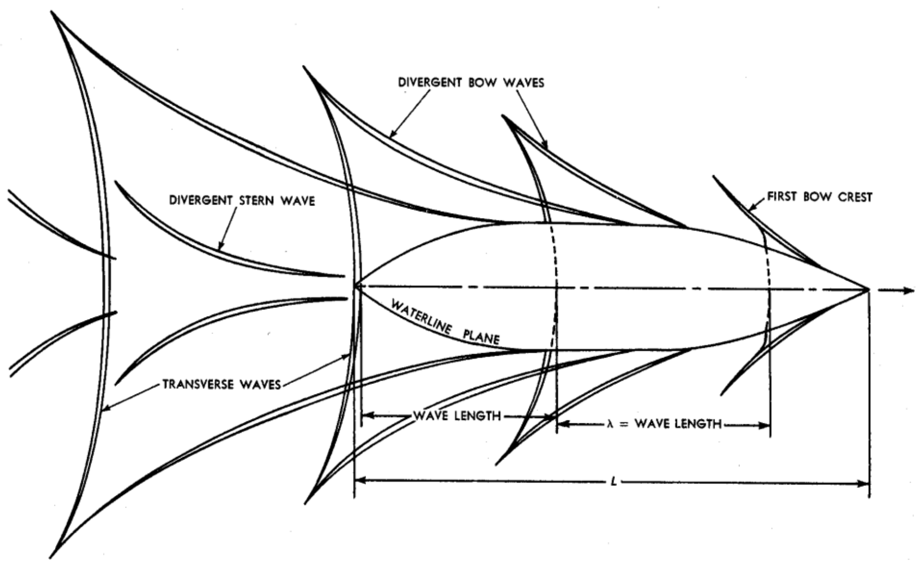

Figure 3.43 Characteristic wave pattern generated by a displacement hull (Gillmer & Johnson, 1982)

Eddy Resistance

Eddy Resistance is the resistance caused due to the formation of eddies particularly at the aft end of the boat because of the separation in the regular flow pattern around the hull (Minami & Yamachika, 2004).

Appendage Resistance

Resistances caused due to the appendages like propellers, rudders and shafts are known as appendage resistance (Minami & Yamachika, 2004).

Air Resistance

Air resistance depends upon the cross-sectional area of the boat above the waterline. It contributes 2 percent of total resistance while in calm weather.

Discussion

With regard to the ENGG180 project all students use a standard motor with a range of propellers. There is little scope for advanced product development for example new propeller or motors. However, mathematical modelling and simulation is possible but it is beyond the scope of first years. The motor characteristics could be mathematically modelled, coupled with a propeller model linked to a hull model, maybe using MATLAB as a simulation tool. It is clear that though an appropriate way of investigating boat performance before building, it is well beyond the level of work expected of first years. It is suggested that if further work is undertaken into advanced product development methods for model boats that simulation and modelling gets a more thorough investigation.

This review section was aimed at understanding the critical elements that result in a fast boat. Clearly this is a complex area beyond the understanding of first year students. It is therefore proposed that an information pack be developed, based on this research to supplement what the students learn in labs. The application of the research found in chapter 3 is demonstrated in chapter 4.

Chapter 4 Design Methodologies

The design of model boat needs to take into account many factors. This chapter discusses engineering design, product development, the components and systems that make up the model boat.

4.1 Engineering Design

The activities required to find solutions to a problem not solved before, or to find a different solution to a previously solved problem by the applying scientific ideas is known as engineering design (Hurst, 1999). ENGG180 students are taught general design methods through a short series of lectures.

4.2 The Design Process

The design of a product is carried out by first examining its need or purpose and then working on it by doing necessary calculations, making models and drawing sketches to make sure the product is the right shape and size so it can be manufactured (Childs, 2004). The design process is classified into different phases as given below.

Conceptual Design

This is the phase where the design is initiated by creating a rough idea of the product, about its performance and functions and thereby developing a number of possible solutions which are later narrowed down to a single best, concept. This phase requires maximum creativity and involves the most uncertainty. Following are the activities of a conceptual design (Dieter, 2000).

- **Identification of needs:** The need for the development of the product is first found from the various available resources and is supplied to the design team (Dieter, 2000).

- **Problem definition:** It is the most important step of the engineering design process. To reach an outstanding solution it is necessary to understand the problem thoroughly, it could be a math problem, production problem or design problem (Dieter, 2000).

- **Gathering information:** The need for information is crucial in a design project; the main source for information can be a published technical literature, books, patents etc (Dieter, 2000).

- **Conceptualization:** A broad set of concepts are generated to potentially satisfy the problem statement. The key activities of conceptualization are team-based creativity methods and efficient information gathering (Dieter, 2000).

- **Concept selection:** The concepts generated are evaluated and then modified to a single preferred concept (Dieter, 2000).

- **Design review:** Before moving to the next phase, the selected design is reviewed to assure the design is physically realizable and economically worthwhile. A detailed product-development schedule is also looked into, to plan a strategy to minimise product cycle time, to find the resource, equipment and money needed to complete the project (Dieter, 2000).

Embodiment Design

This stage involves the structural development of the design concept. The main functions to be performed by the product are considered, and decisions are made on the size, shape, strength, material selection and spatial compatibility. Any major changes beyond this can become very expensive. Major tasks of embodiment design are product architecture, configuration design and parametric design (Dieter, 2000).

- **Product architecture:** The overall design is divided into modules or subsystems in product architecture. At this stage the arrangement of physical components of system are decided, to carry out the functional duties of design (Dieter, 2000).

- **Configuration design of parts and components:** Parts incorporate various features like holes, curves and splines which have to be arranged in space relative to each other. To check out the spatial constraints, modelling and simulation may be performed at this stage (Dieter, 2000).

- **Parametric design of parts and components:** The exact dimensions and tolerances are established, the design robustness of part, assembly and system are analysed at this stage. The decisions on material and manufacturing process are also taken at this stage, if not done before (Dieter, 2000).

Detail Design

Detailed computer-generated engineering drawings suitable for manufacturing are prepared. These drawings may be 2-dimensional or 3-dimensional solid models.

4.3 Product Development

The concept of designing, manufacturing and the selling of a product is known as product development (Mital et al, 2008)

4.4 Characteristics of Successful Product Development

A successful product is one which can be produced and sold profitably, but profitability is difficult to access quickly and directly. So to access the performance of a product the following specific dimensions are used (Ulrich & Eppinger, 2004).

- **Product quality:** How good is the product, its ability to perform its functions, reliability are some of the factors which define product quality. The quality of the product is ultimately reflected in its demand in the market (Ulrich & Eppinger, 2004).

- **Product cost:** Is the cost of manufacturing the product, which includes spending on capital equipment, tooling, material cost and labour costs (Ulrich & Eppinger, 2004).

- **Development time:** How fast the team can complete product development determines how sharp the company can be to compete with its competitors and to technological developments (Ulrich & Eppinger, 2004).

- **Development cost:** The money which the company had to spend to develop the product (Ulrich & Eppinger, 2004).

- **Development capability:** It is the ability of the company to develop future products with the experiences in previous development projects (Ulrich & Eppinger, 2004).

4.5 Computer-Aided Engineering

The application of computers in the engineering process is known as Computer-Aided Engineering (CAE). Computer-aided engineering can be classified into computer-aided design (CAD) and computer-aided manufacturing (CAM).

The arrival of the computer has brought a vast change in the way engineering design is practiced. The greatest impact of Computer-Aided Engineering has been on engineering drawing. The ability to modify an existing drawing by making ready modifications is a great saving in time. These days three-dimensional modelling is widespread and is available on desktop computers, these three-dimensional models provide a complete mathematical and geometrical characterization of the part geometry. Such models are very rich in essential information that it can be used for analysis, design optimization, simulation, rapid prototyping and manufacturing (Dieter , 2000).

Computer-Aided Design (CAD)

Designing process supported by computers is known CAD, which usually refers to 2D drafting, 3D modelling and related applications.

Computer-Aided Manufacturing (CAM)

The application of computers in manufacturing process of any product given is known as CAM. Computer-Aided Machining bridges the gap between the CAD design and the finished product, by converting the CAD design into a set of manufacturing instructions. More about the manufacturing procedure is given in the next chapter.

4.6 Model boat components and systems

The structure and design of a model boat comprises 3 main areas as given below:

- Drive system
- Electrical system
- Hull

Each of the above mentioned design areas consist of various components and systems and are inter-related and depend on the design of other components.

4.6.1 Drive System

The drive system available for ENGG180 project is an inboard drive. It was decided to go for a twin drive system as twin drive system have more power than would be available from a single drive. Another reason for using twin drive was to avoid the need for a rudder as twin drives can also control the steering by varying the speed of the drives. The main parts of drive system consist of:

- DC motor
- Shaft
- Propeller

The Figure 4.1 shows the CAD model of the drive system.

Figure 4.1 CAD model of the drive system

DC Motor

The torque required to propel the boat is supplied by a 3 pole DC motor. The motor specification from the manufacturer is given in Table 4.1.

Model	Voltage		NO LOAD		AT MAXIMUM EFFICIENCY					
	OPERATING RANGE	NOMINAL	SPEED	CURRENT	SPEED	CURRENT	TORQUE		OUTPUT	EFF
			RPM	A	RPM	A	oz - in	g - cm	W	%
RE - 540	3.0 - 9.0	3.6v CONSTANT	8400	0.80	8350	5.71	1.87	135	11.6	56.4
RE - 540	3.0 - 9.0	6.0v CONSTANT	14000	1.00	10800	7.10	3.5	254	28.1	66.0

Table 4.1 Motor Specification

Motor Experiments

An experiment was conducted to find the motor torque and rpm at different voltages. Figure 4.2 shows the RPM versus Torque graph for the DC electric motor.

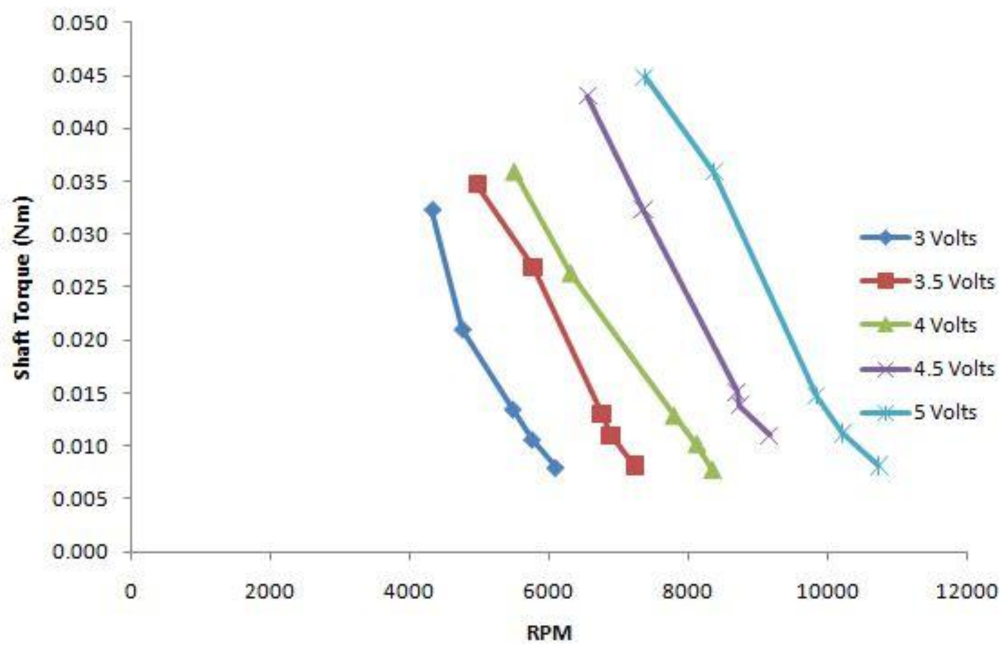

Figure 4.2 Shaft Torque versus RPM graph

Shaft

The purpose of the drive shaft is to transmit the torque from motor to the propeller. This shaft is enclosed in an aluminium tube, which acts as a drive shaft casing; one end of the shaft is connected to the motor using a silicon tube and inserts (as a pseudo-universal joint), and to the other end is connected the propeller.

Propeller

Three propellers are available from the sponsor for the model boat. The dimensions of the propellers are given in the following Table 4.2.

Propeller #	Diameter (mm)	Pitch
1	50	1.2
2	50	1.4
3	50	2.0

Table 4.2 Propeller Dimensions

The propellers available were of constant diameter but with different pitch. Dimension analysis test was performed to find the best propeller suited for the purpose, under controlled conditions. The experiment consisted of a cylinder filled with water in which the propeller was immersed, which was connected to the DC motor. This motor was attached to a wire, running through a pulley system with a small weight attached to it. The motor was supplied with a voltage ranging from 2 volts to 4.5 volts. The forces exerted by the propellers at different voltages were calculated. Figure 4.3 shows the force versus voltage graph and the Figure 4.4 shows the current versus voltage graph for the three propellers.

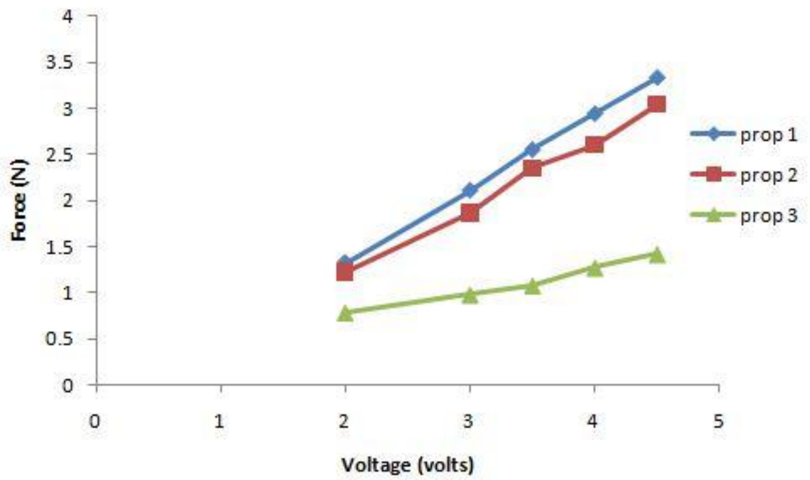

Figure 4.3 Force versus voltage graph

The force produced by the propeller 1 was greater than the other two propellers for the same voltage, propeller 3 with more pitch produced the least force.

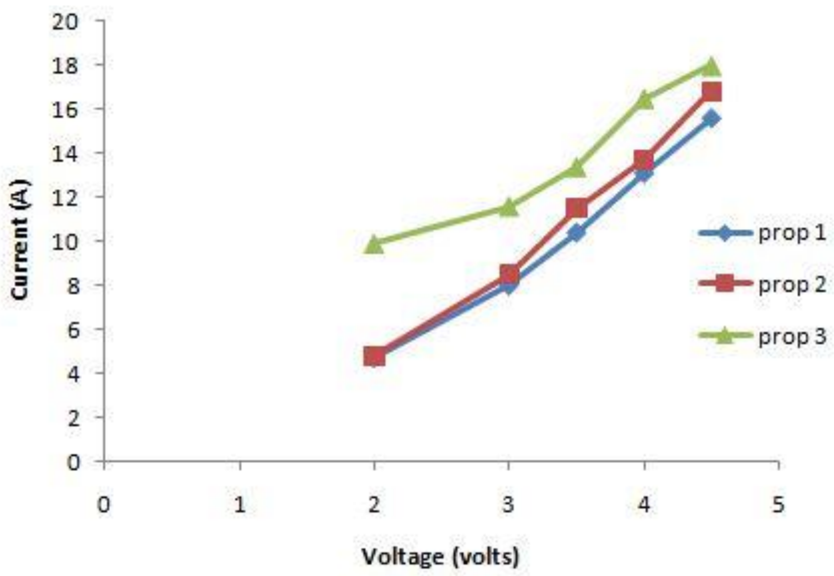

Figure 4.4 Current versus voltage graph

Propeller-3 drew maximum current while propeller-1 drew the least current, for the same voltage.

From the experiments conducted, it was concluded that propeller-1 was the ideal choice for the boat to be made since it produces maximum force and draws the least current from the three available propellers.

4.6.2 Electrical System

The electrical system consists of

- Batteries
- Microswitch
- Servo motor
- Transmitter and Receiver unit
- Circuit Diagram

Batteries

Since the maximum operating voltage of the DC motor was 9V, the motor was supplied with 9V with 6 batteries connected in series; it was observed that at no-load the voltage dropped to 6V and when the propeller was immersed in water the voltage further dropped to 2.5V. This drop in voltage was mainly due to the high current drawn by the motor and also because of the internal resistance of the batteries. To avoid this huge voltage drop, the batteries were connected in series-parallel connection, but to provide 9V would require 12 numbers of batteries for each motor which will increase the boat weight too much. So it was decided to supply 6V to each motor from 8 numbers of batteries connected in series and parallel connection.

The model boat requires three packs of batteries; two sets each containing eight numbers of c-size batteries to supply power to the motor and one set of four AA batteries for the receiver and servo motors.

Microswitch

A Microswitch is a small electric switch used to cause an on/off action like any other switch and is actuated by a small physical force. The purpose of micro switches in model boat is to close the circuit to the motor and change the polarity of motor for steering purpose.

Each motor requires three micro switches, one to close the circuit and the other two to reverse the polarity of current to the motor for steering.

Servo motor

The physical force required to activate the micro switch is provided by the servo motor, which is controlled by the remote control.

Two servo motors are used; one servo motor to activate the two micro switches to close the circuit to both the motors and the other servo motor to activate the four micro switches used for steering, to reverse the polarity of current.

Transmitter and Receiver unit

A 3-channel transmitter is used to supply signals to the servo to control the boat. This signal supplied by the transmitter is received by the receiver unit which is fixed inside the boat. As already mentioned, the power for receiver unit is supplied from a set of four AA batteries. Both the servo motors are connected to the receiver unit.

Circuit Diagram

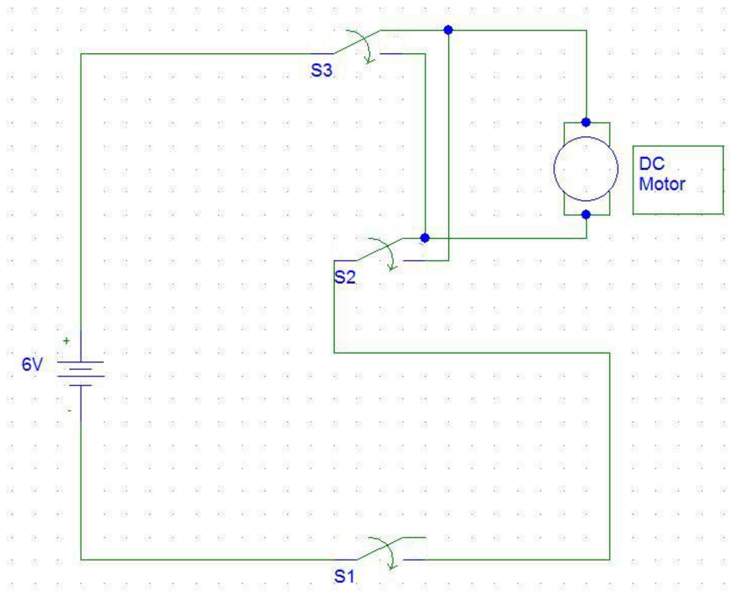

Figure 4.5 Circuit diagram of the electrical system

Figure 4.5 shows the circuit diagram for the electrical system; where S1, S2 and S3 are three micro switches. A servo motor is used to activate S1 and another servo motor is used to activate both S2 and S3 simultaneously. S1 is the main switch which has to be in the ON position for the circuit to be complete. With S2 and S3 in the original position, when S1 is closed the circuit is completed and the motor runs clockwise, propelling the boat in forward direction. Figure 4.6 shows the circuit diagram when the motor is running in clockwise direction.

The purpose of S2 and S3 is to reverse the polarity of the current to the motor, so the motor rotates in the opposite direction by which the boat can be steered. S1 being closed, when S2 and S3 are changed (simultaneously) using the servomotor, the polarity of current to the motor changes and the motor rotates in the opposite direction. Figure 4.7 shows the circuit diagram when the current polarity is reversed.

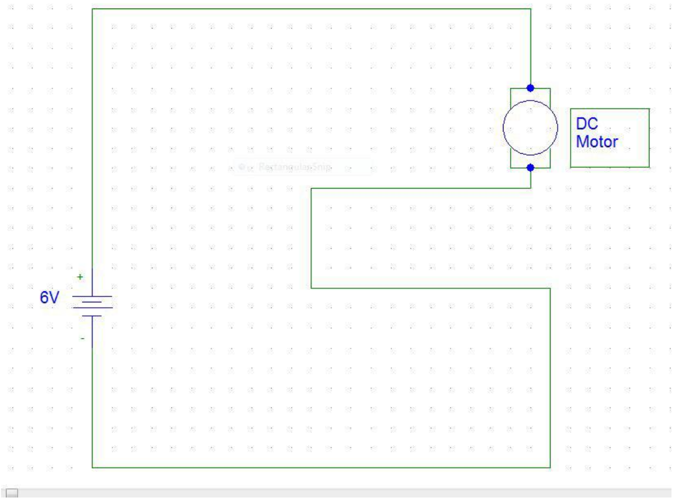

Figure 4.6 Current flow when the boat is propelled in forward direction

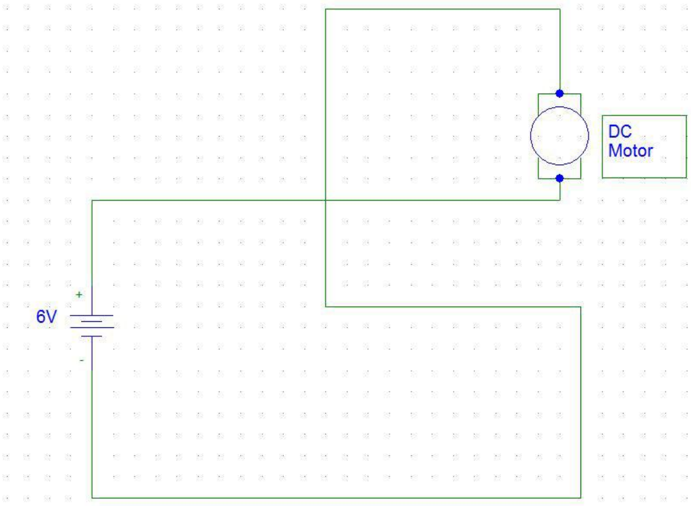

Figure 4.7 Circuit diagram when polarity of current to motor is reversed

4.6.3 Hull

The hull is the watertight body of the boat and its shape depends upon the needs of design. The model boat hulls are usually made up of wood, fibreglass or plastics. While the introduction of plastics has boosted the production of smaller models, the popular ones are still wood and fibreglass (Finch, 2001).

The main problems with the existing hull designs made by undergraduate engineering students were that they lack the features of a model speed boat which resulted in an increase drag. In some of the existing designs the hull had a rounded chine instead of hard chine, lifting strakes were not incorporated in the deep-v hulls designs, and the bow was not sharp enough to cut through the water. So there was a need for a hull design with the features incorporated for maximum speed and a better efficiency. Before starting the hull design it is necessary to know the approximate weight of the boat, which is essential for the designing.

Boat Weight Calculation

The Table 4.3 shows the items used for the model boat manufacturing and their weights, some of the weights are approximated.

Product	Weight per unit (gm)	No of units	Total weight (gm)
Battery (C-size)	70	16	1120
Motor RE-540	160	2	320
Servo motor	36	2	72
Micro switch	8	6	48
PETG sheet (Hull)	630	0.5	315
TPS sheet (Deck)	538	0.5	269
Shaft and its accessories	100	2	200
Battery (AA)	20	4	80
Unaccounted parts			500
Total weight	2924 gm ~ 3Kg		

Table 4.3: Parts and accessories with their weight

The unaccounted parts include electrical cable, receiver unit for the transmitter, battery holders and other small parts and accessories.

Hull Design

From the different research of chapter 3, it was decided to go for a shallow-v hull. The other designs were eliminated because, for a deep-v hull the wet surface area is more which increases drag at slow speed compared to shallow-v, for a catamaran the cost of building is more as it consist of two hulls. Unfortunately there was no simple formula for calculating the drag coefficient of the hull. The boat that could be achieved was to apply the ‘rules’ for fast boat design. Without the drag coefficient the maximum speed of the boat could not be calculated. However, the boat was designed to plane if enough propulsion could be achieved.

The shallow-v hull was designed with eight degree constant deadrise, a sharp bow, hard chine and a flat transom. The hull was designed with enough room to fit in the interior parts which include motor, batteries, shaft and other electronic components. The upper part of the hull had an extended lip of 25mm for the deck to be glued into. The overall length of hull excluding the lip was 550mm which was the maximum length permitted as per ENGG180 rules, the beam at transom was 170mm. As already mentioned the boat is designed for a displacement of 3 kg, so for the boat to float it has to displace 3 kg of water. Next step is to calculate the draft required for the mentioned displacement, length and beam.

Draft Calculation

Wight of the boat = 3kg

Length Overall (LOA) = 550mm

Beam = 170mm

Density of water $\rho = 1000 kg/m^3$

$\rho = m / v$

$1000 = 3 / (.55 \times .17 \times h)$

Where ‘h’ is the draft.

h = 0.32mm ~ 30mm

From the above calculation we got the draft i.e. the depth of the hull under waterline, but the total height of boat is the sum of draft and freeboard. The freeboard was decided to be 50mm at aft to keep the deck dry. So the total height at transom was 80mm.

With these measurements, the 3-D hull model was designed in Solidworks as shown in the Figure 4.8. The assembled CAD model of the boat is shown in Figure 4.9.

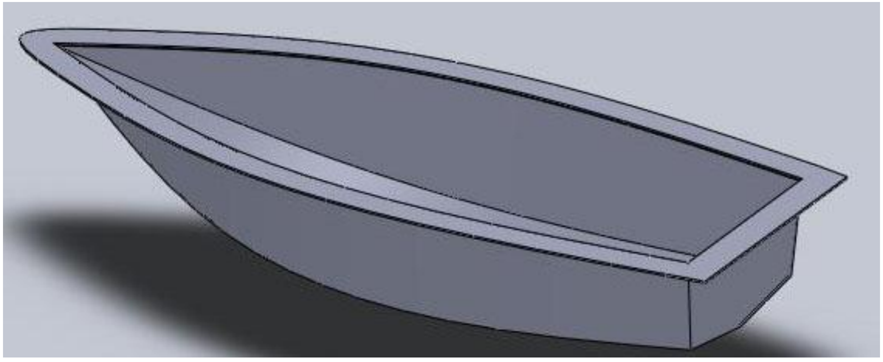

Figure 4.8 Hull CAD model

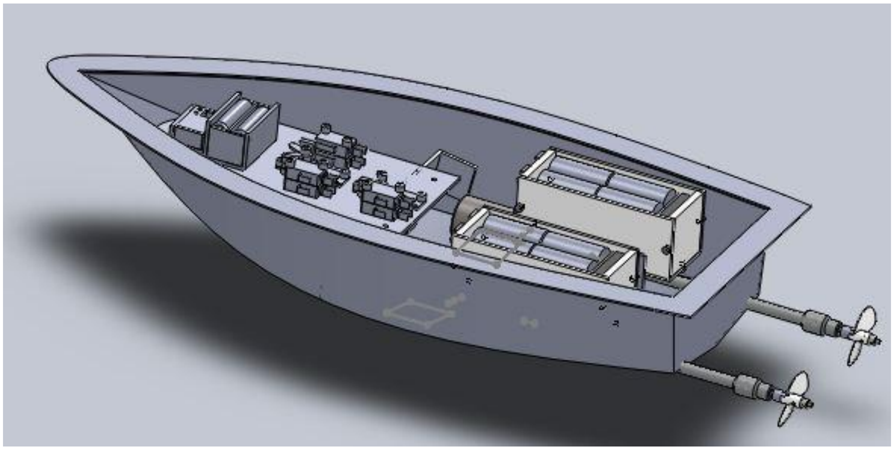

Figure 4.9 Boat CAD model

Discussion

The finished design, in particular the hull was with the research results of chapter 3. The weight has been kept to minimum of 3 kg. It is expected that with this design the boat will plane if enough propulsion is available.

Chapter 5 Manufacturing Methodologies

This chapter discusses about the various manufacturing methods available for the model boat building.

5.1 Manufacturing

Manufacturing is the process of converting raw material by adding value to it, changing its geometry and properties to form a desirable product. To change the appearance and properties of raw material requires application of physical and chemical process. Products are manufactured by employing a combination of machine tools, cutting tools and manual labour. These products later assembled with the support of automated equipments or manual effort result in the final product. Raw materials before reaching the final stage undergo specific activities such as milling, grinding, turning, welding etc known as manufacturing processes. (Mital et al, 2008).

These days, manufacturing is not only about converting raw materials to desirable product but also to produce it quickly, economically, easily and efficiently; along with that the product should also be desired by the end user. Manufacturing and production are often confused and used interchangeably; while manufacturing refers to converting raw materials to desired products by using various shaping techniques, production is generally referred to outputs.

5.2 Manufacturing Methodologies

When considering the modern manufacturing process for the work, the following technologies were investigated.

- CNC Machining
- Rapid Prototyping
- Laser cutting

CNC milling and rapid prototyping are the some methods which can be employed to build the model boat. As already mentioned in the second chapter, for

ENGG180 project, the undergraduate engineering students employ conventional hand tool methods to build the hull.

Figure 5.1 shows the design and manufacturing procedure employed by the students. The students are briefed about the boat design through lectures, lab demonstrations and taught the rules to be followed. Some background research work is carried out by students before they develop their boat concept designs. A concept design is selected and modelled in CAD. The profile is manually sketched on a thick block of polystyrene, to cut and form the mold. When the model is sketched on the block, and cut manually, the CAD data is lost and causes lack of accuracy. In certain cases it was also observed that students make a sketch initially and the CAD modelling was done after the mold was made. This mold is used to make the hull using vacuum forming. The other components are handmade and assembled in the hull. The finished boat is tested on race day.

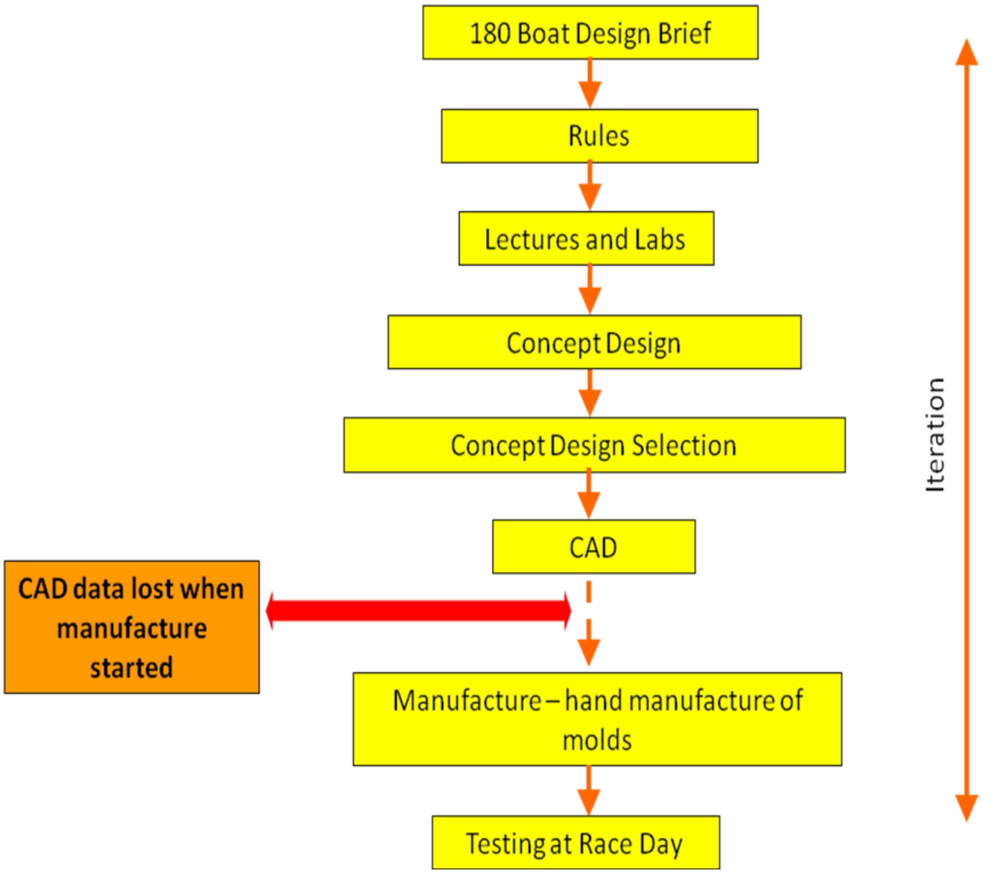

Figure 5.1 The design and manufacturing cycle of ENGG180 boat project

It was found that, the modern product development process (Figure 5.2) was not effectively used in this project. Though a CAD model was made, none of the parts were made directly from the model. No simulations of boat performance is done due to the lack of available resources in the university, time constraints and most importantly that the CAE process is beyond the scope of the first year students.

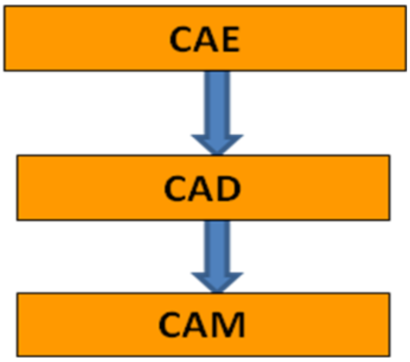

Figure 5.2 Computer-aided engineering

5.2.1 Computer Numerical Control Machining

Computer Numerical Control (CNC) is a computer-assisted process which controls the machines, from instructions generated by a processor. Numerical Control means controlling the machine by numbers. CNC can be used in any type of machine that requires direction by human intelligence (Madison, 1996).

Both computers and computer numerical control (CNC) systems have brought remarkable changes to the machining industry. Combinations of CNC and new machine tools have helped industries to produce parts consistently with high speed, greater accuracy, repeatability and efficiency. Computers are used in the manufacturing process for part designing by CAD and to control or supervise machine tools.

Computers receive the input data from the users through different input devices. This data is then processed and the output produced controls the machine tool.

Advantages of CNC

CNC has grown dramatically in the past few years and is still growing because of its many advantages:

- **Accuracy:** Modern CNC machines can produce work pieces of high accuracy, which are accurate to within a tolerance of 0.0025 to 0.005mm. Such accuracies are impossible even for a skilled machinist with years of experience (Krar et al, 2005).
- **Reduction of scrap:** The high accuracy of the CNC system drastically reduces the scrap (Krar et al, 2005).
- **Complex machining operations:** Even complex shapes can be machined without compromising on time and accuracy (Krar et al, 2005).
- **Increased productivity:** Since the entire machine functions are controlled by CNC, very less setup and lead time are required increasing the productivity (Krar et al, 2005).
- **Greater machine utilization:** The less time required for setup and operator adjustments gives the advantage of increased product rates of up to 80% (Krar et al, 2005).
- **Fewer chances of human error:** The need for trial cut, trial measurements, positioning movements and changing tools by the operator are mostly reduced or eliminated by the CNC program (Krar et al, 2005).
- **Less inspection time required:** the parts produced are of high accuracy and uniform quality so the inspection time required is very less (Krar et al, 2005).

5.2.2 Rapid prototyping

Rapid prototyping is a forming process which manufactures parts layer by layer directly from its digital representation in a CAD/CAM system in a very short time. Rapid prototyping manufacture parts by addition of material rather than removal of materials like in CNC or conventional methods. Rapid prototyping technology has been successfully used in industries of automotive, aerospace, electronics etc (Lan, 2009). Rapid prototypes are made directly from the CAD models as shown in the Figure 5.3. Rapid prototyping methods:

- Stereolithography (SLA)
- Laminated Object Manufacturing (LOM)
- Fused Deposition Modelling (FDM)
- Selective Laser Sintering (SLS)

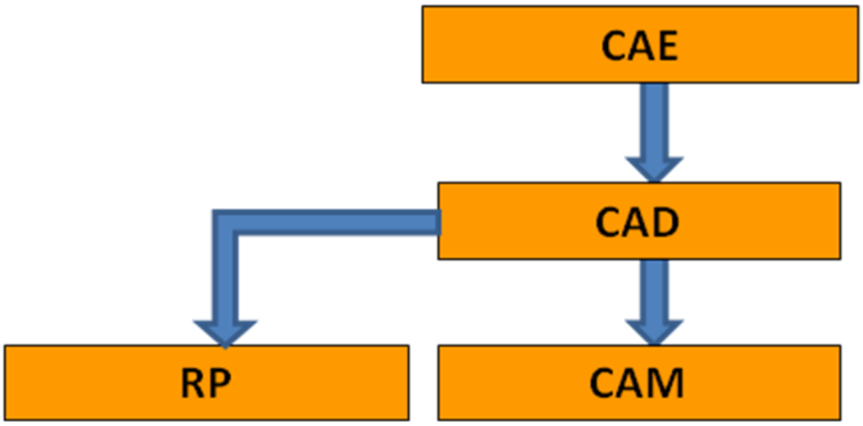

Figure 5.3 Rapid prototyping from CAD model

Stereolithography (SLA)

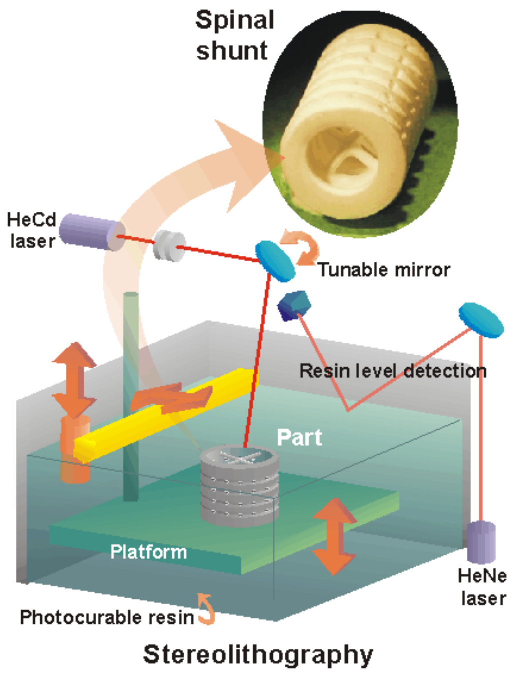

Figure 5.4 Stereolithography (source www.princeton.edu)

Stereolithography is a widely used rapid prototyping technology (Figure 5.4). It is an additive process where a computer controlled laser is used to cure a photo-sensitive resin layer by layer. The laser causes photo-polymerisation, and the liquid resin is converted to solid (Huang & Lan, 2005). Figure 5.5 shows a part manufactured by Stereolithography.

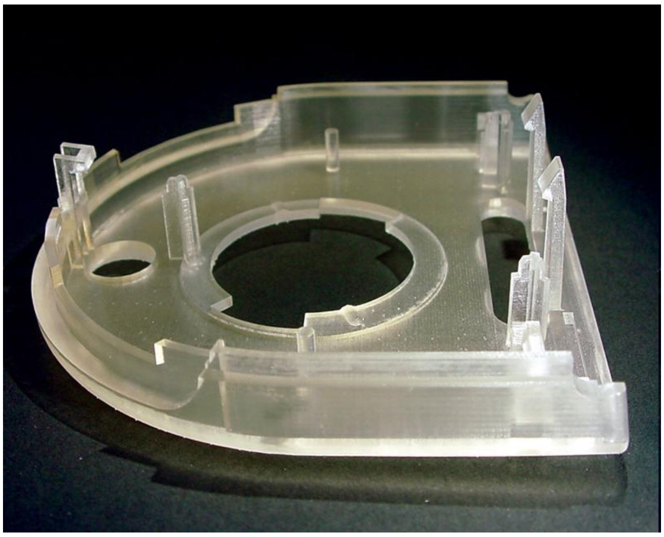

Figure 5.5 A part manufactured by Stereolithography (source: ENME480)

Laminated Object Manufacturing (LOM)

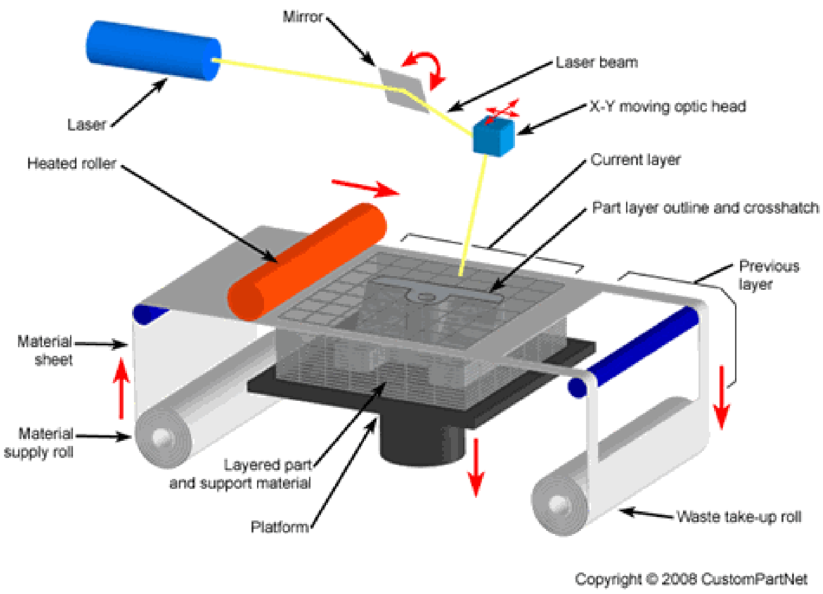

Figure 5.6 Laminated Object Manufacturing (source www.custompartnet.com)

In LOM scanning laser is used to cut cross-sections from glue-backed material (usually paper). The material in the form of sheet is advanced over a build platform where it is pressured to bond to the layer below by using a heated roller. These layers are cut using a laser to form the shape of part directly from the CAD model. When the layer is cut the platform lowers by a depth equal to the sheet thickness and the next sheet is brought on top of this layer to continue the process until the part is completed. The part formed have an appearance similar to that of wood. Applications of LOM are in sand casting, investment casting and ceramic process (Mueller & Kochan, 1999). LOM process is shown in the Figure 5.6; the prototype of a crankshaft made by LOM is shown in Figure 5.7.

Figure 5.7 A crankshaft fabricated on LOM (source: ENME480)

Fused Deposition Modelling (FDM)

FDM is another layered prototyping method using hot glue gun to make the parts. In FDM process (Figure 5.8), plastic or wax material is extruded through a thin nozzle and fused together layer by layer to form the 3D model. Resistive heaters are used in nozzle to keep the plastic above its melting point to help it flow freely. The plastic after flowing from the nozzle bonds to the layer below and hardens immediately. Some of the parts made by FDM are shown in Figure 5.9

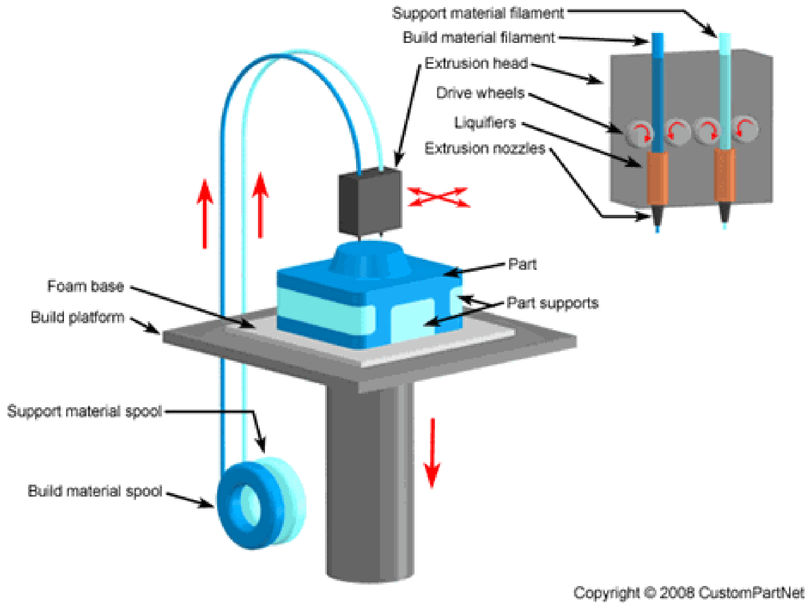

Figure 5.8 Fused Deposition Modelling (source: www.custompartnet.com)

Figure 5.9 Parts made by FDM (source: ENME480)

Selective Laser Sintering (SLS)

In SLS process (Figure 5.10), the part is made by selectively diffusing small particles of plastic, metal, ceramic or glass powder layer by layer using a laser. Preheated powder is rolled on to the platform; the powder is maintained at an elevated temperature so that it fuses easily on exposure to laser beam. The computer controlled laser beam scans the powder surface to bind them together to form the corresponding cross section of the product, the temperature of the powder rises above glass transition point and the adjacent particles flow together. After each layer is made the platform adjust its height equal to the thickness of the layer built, additional powder is then put on each solidified layer until the part is made (Dong et al, 2009). A Child's car seat assembly made from thermoplastic by SLS process is shown in Figure 5.11.

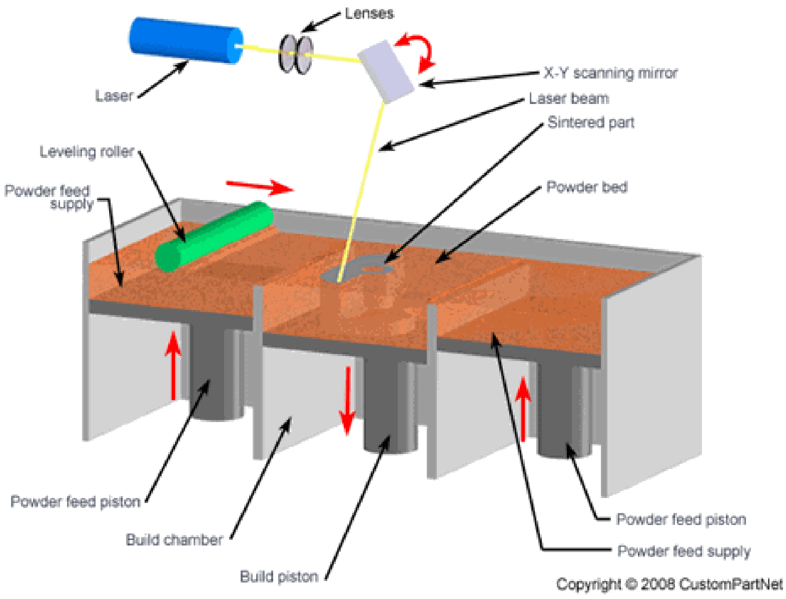

Figure 5.10 Selective Laser Sintering (source: www.custompartnet.com)

Figure 5.11 Thermoplastic SLS part (source ENME480)

5.3 Application of advanced Manufacturing to Model Boat

Laser Cutting

Laser cutting is a thermal process used to cut complex shapes on thin sheet metals using a laser beam. It has become a common industrial process these days. Automotive industries use laser cutting to trim sheet metals which are shaped later on (Lamikiz et al, 2005). Recently, the application of laser cutting has also spread to non-metallic materials like polymers and ceramics (Dubey & Yadava, 2008).

Laser Cutting Process

The laser beam is concentrated to a small spot by a lens system to form high energy density at the spot (Figure 5.12). This high power heats the material either to its melting point or vaporisation temperature and thereby cut the material. Since the cutaway path is vaporised, further hand labour is usually eliminated. The quality of cut depends on the thickness of the material being cut, cutting speed, laser power etc.

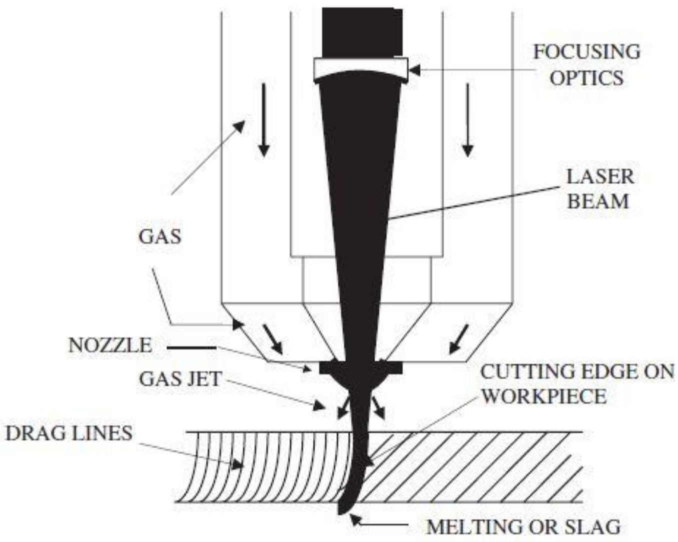

Figure 5.12 laser cutting process (Dubey & Yadava, 2008)

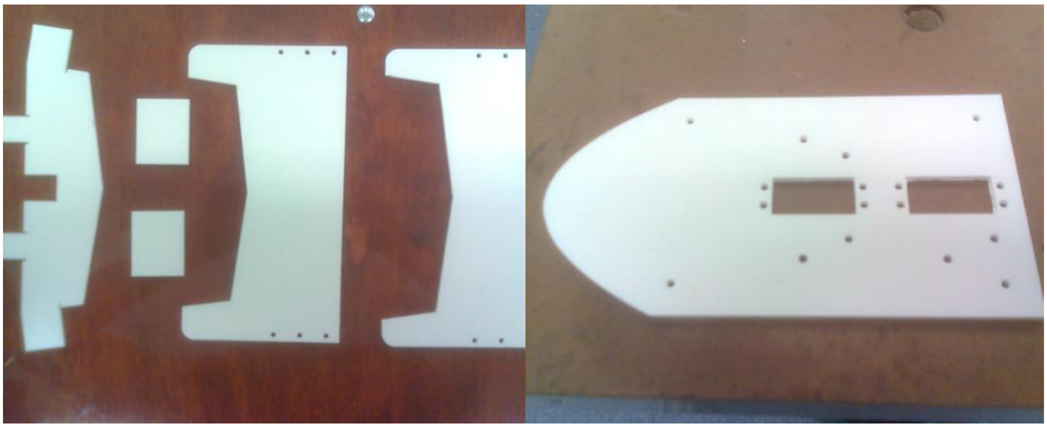

Figure 5.13 Some thermoplastic parts cut by laser cutting

The many small thermoplastic parts (Figure 5.13) required for the model boat was cut using the laser cutting machine from thermoplastic sheet, directly from the CAD drawing. The laser cut parts were then bent to the required shape using a thermoplastic bender. The CO_2 laser cutting machine used for the cutting operations is shown in the Figure 5.14

Figure 5.14 Laser cutting machine

The Mold

The mold for the hull was machined in a 3-axis CNC milling machine (Figure 5.15), for which a MDF block was made by gluing 6 layers of MDF of 18mm thickness, 590mm long and 250mm wide to form a block of 108mm thick. This block was screwed to another layer of MDF of a bigger dimension, to clamp it to the machine table as shown in the Figure 5.16.

Figure 5.15 CNC Milling machine

Figure 5.16 MDF block clamped to table for machining

The CAD design was fed to the computer system; the design was converted to the machine language to control the operations and execute its instructions using edge cam software. Three tools were used for machining, one for rough cutting and the other two for the finishing operation. The process took two hours to machine the block. The different stages of forming the mold by CNC milling is shown in Figure 5.17. This machined mold had a rough finishing so it was sanded and applied with two coats of varnish to avoid any imperfections and also to make the surface smooth as shown in Figure 5.18. By using CNC milling technology it was possible to produce the mold accurate to the CAD model.

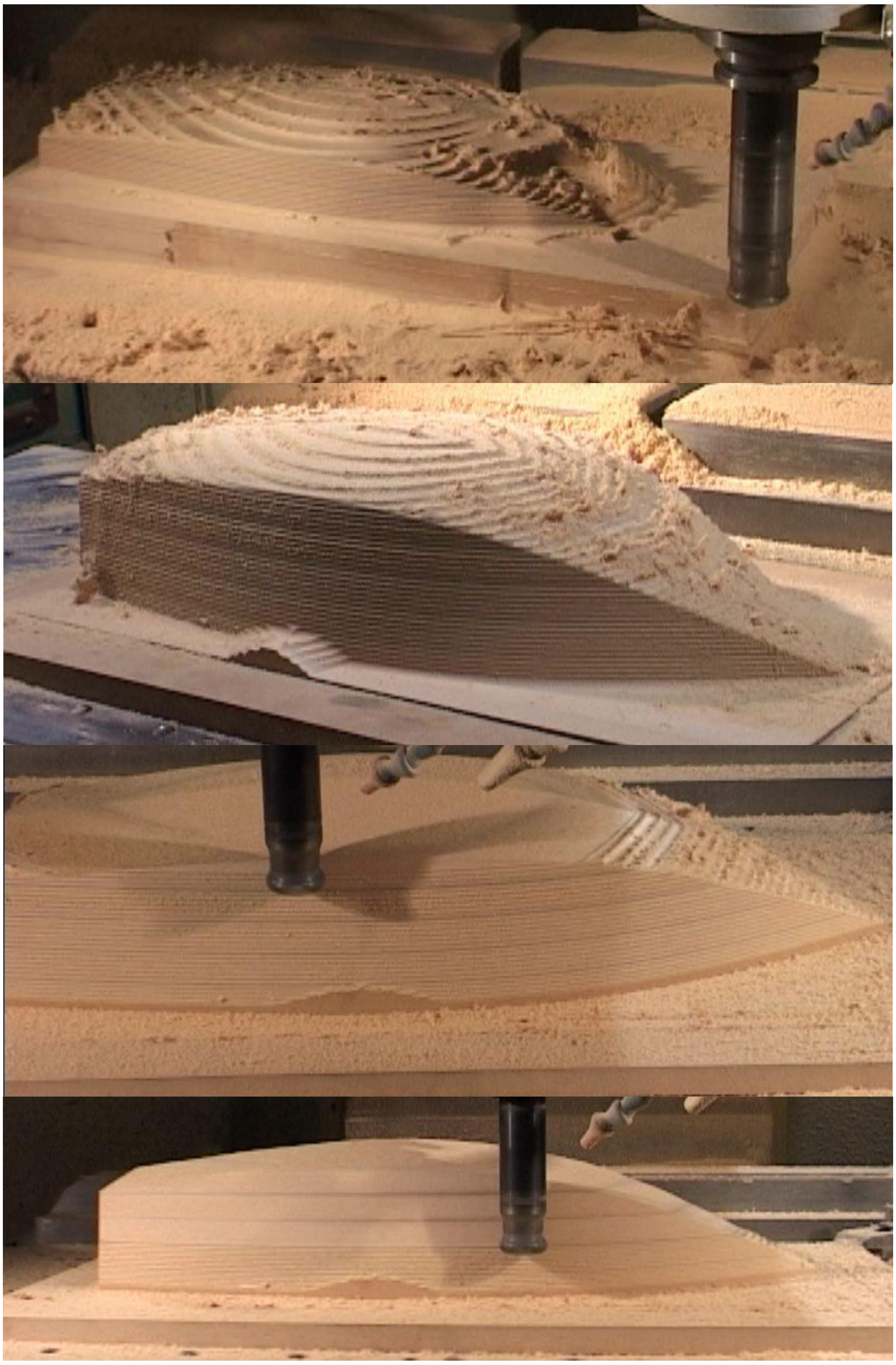

Figure 5.17 The different stages of the mold from a rectangular block to CAD model

Figure 5.18 Mold sanded and coated with varnish

This mold was used to form the hull from 1.5mm thick PETG by vacuum forming process. The formed hull was trimmed from the sheet using a cutting tool leaving a 25mm lip.

Thermoplastics bender

Thermoplastic bender (Figure 5.19) is a device used for bending thin plastics sheets of thickness ranging from 0.5mm to 6mm, by heat softening a narrow width of sheet.

Figure 5.19 Thermoplastic bender

Motor holder

The DC motor requires a mount to which it can be fastened, a CAD design of the motor mount was made as shown in Figure 5.20. This design was exported to the laser cutting machine to cut it from a 3mm thick thermoplastic sheet. This part was later bend using the thermoplastic bender. The DC motor was then fastened to the mount as shown in the Figure 5.21. For two motors, two mounts were made, since it was cut by laser cutting, the part was accurate to the design and no further machining was required.

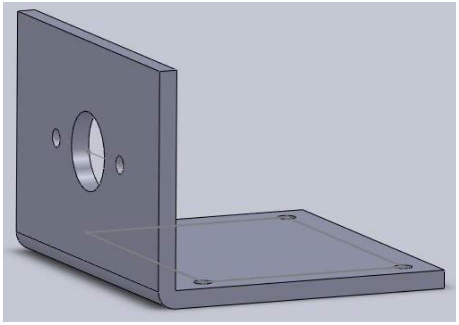

Figure 5.20 CAD model of the motor holder

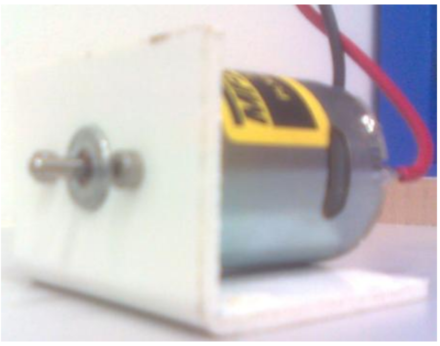

Figure 5.21 Motor fastened to the holder made

To the motor was connected the drive shaft and the accessories. The motor holder was glued to the hull bottom and the drive shaft was bored through the transom to connect to the propeller as shown in the Figure 5.22

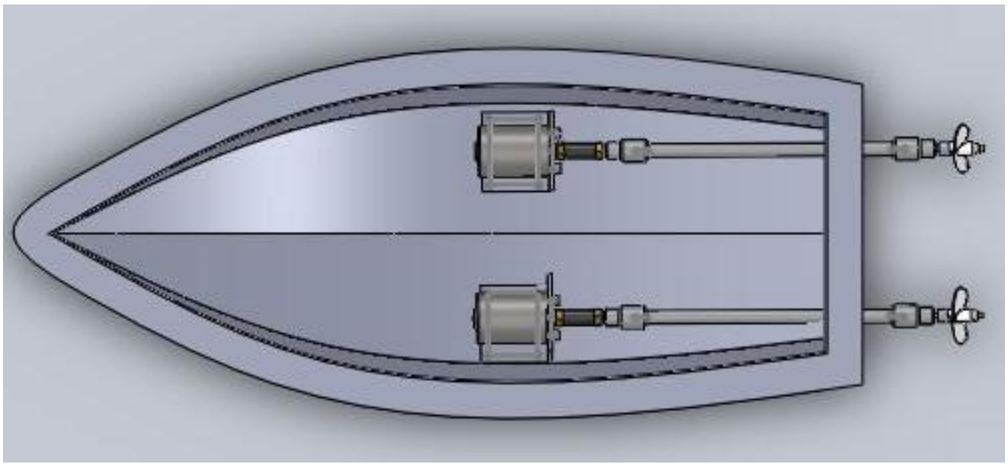

Figure 5.22 Drive system fixed to hull

Battery Pack

Two battery holders were required to hold the batteries for the motor. A CAD model was made for the battery packs, which was to be made from 3mm thick thermoplastic sheet.

The CAD model was imported to laser cutting machine where the thermoplastic sheet was cut to the dimensions and later bend using the thermoplastic bender to form a cuboids shape with three of its sides open. The ends of the battery pack were closed with 6mm thick PVC and the third side was left open to facilitate the batteries. To one of the end side was connected the terminals and the other end had a sponge strip to give the action of spring; to the sponge was glued aluminium bar for the connection between batteries. The batteries were arranged in series-parallel connection. Figure 5.23 shows the CAD model of the battery pack and the Figure 5.24 shows the manufactured battery pack.

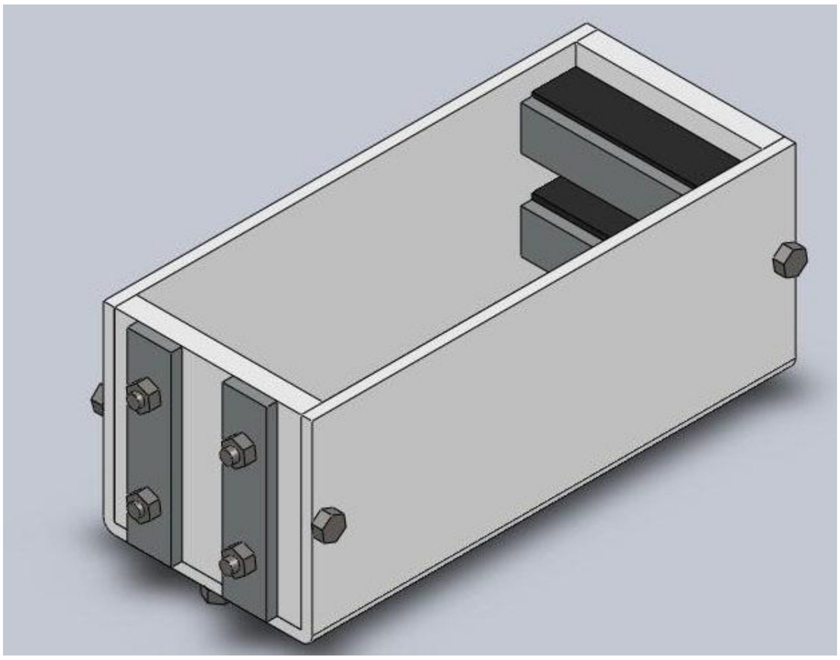

Figure 5.23 CAD model of the battery holder

Figure 5.24 Battery holder made to the model designed

Electrical gear holder

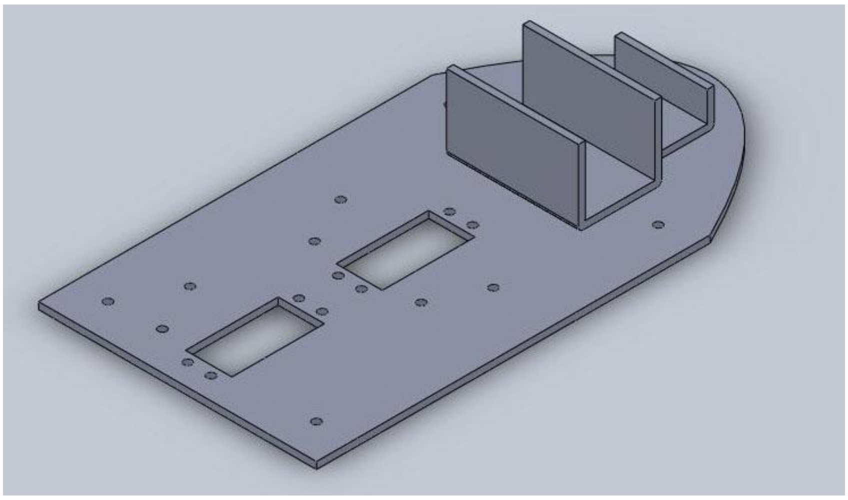

Figure 5.25 CAD model of the electrical gear holder

The electrical gears which include the microswitches, servo motors, receiver unit and the battery pack for the receiver unit needed a holder to which the gears could be fastened to. Figure 5.25 shows the electrical gear holder designed in CAD. The holder consists of three parts, a holder for receiver unit, a holder for AA battery pack, and the base part to which both these holders were glued to and rest of the electrical gears are fastened.

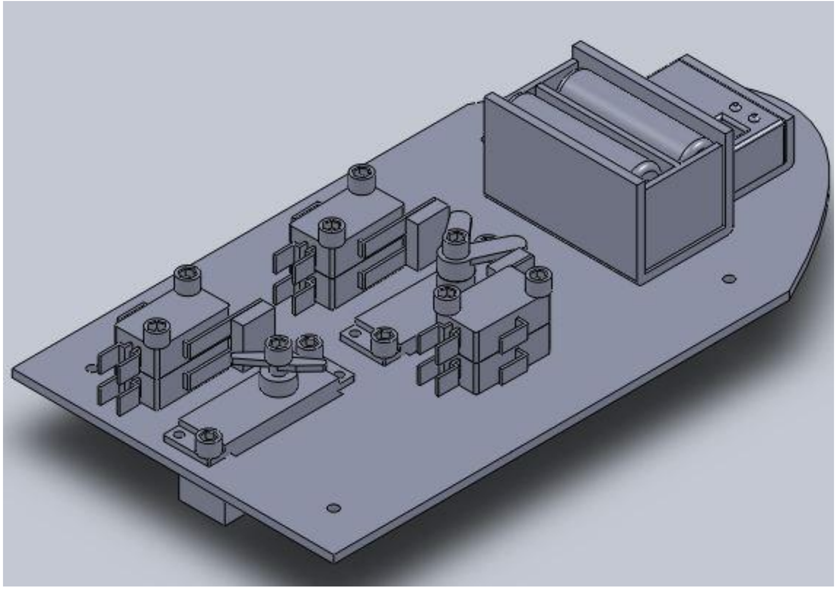

Figure 5.26 CAD model of the electrical gears assembled

Deck

A flat deck was made from 1.5mm thick polystyrene sheet, which was glued to the 25mm lip on the hull. The deck consisted of 3 parts; a lid (Figure 5.27) which can be opened for access to the internal parts of the boat, a support (Figure 5.28) for lid which was glued underneath the deck, this support acts as a seating for the lid, and finally the deck itself (Figure 5.29). CAD designs were made for all the three parts to cut them from 1.5mm thick polystyrene sheet using the laser cutting machine.

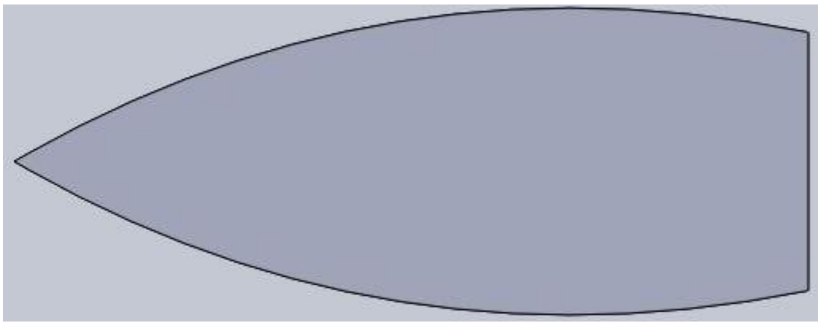

Figure 5.27 CAD model of the Lid

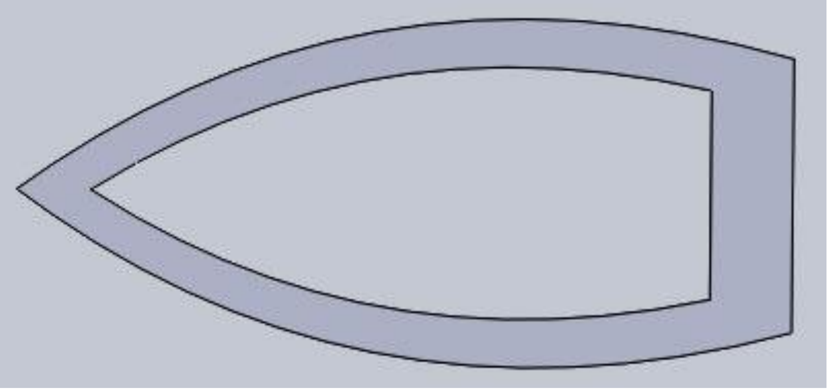

Figure 5.28 CAD model of the support for lid

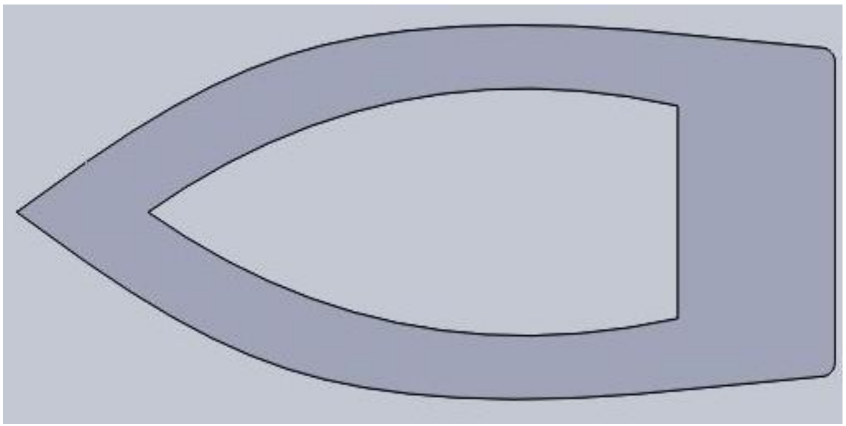

Figure 5.29 CAD model of the deck

Assembling

The internal parts which consist of drive system, electrical system, batteries were assembled as shown in the Figure 5.30.

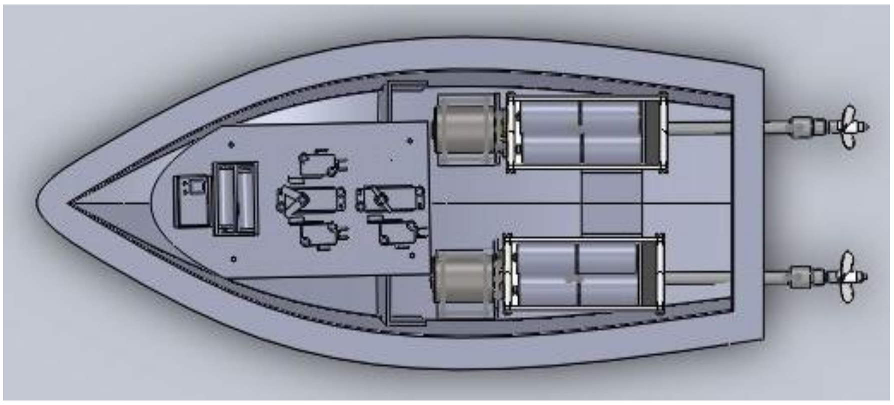

Figure 5.30 CAD model of the boat assembly

Figure 5.31 shows the side view of the boat made and assembled and Figure 5.32 shows to top view of the boat.

Figure 5.31 Boat side view

Figure 5.32 Boat top view

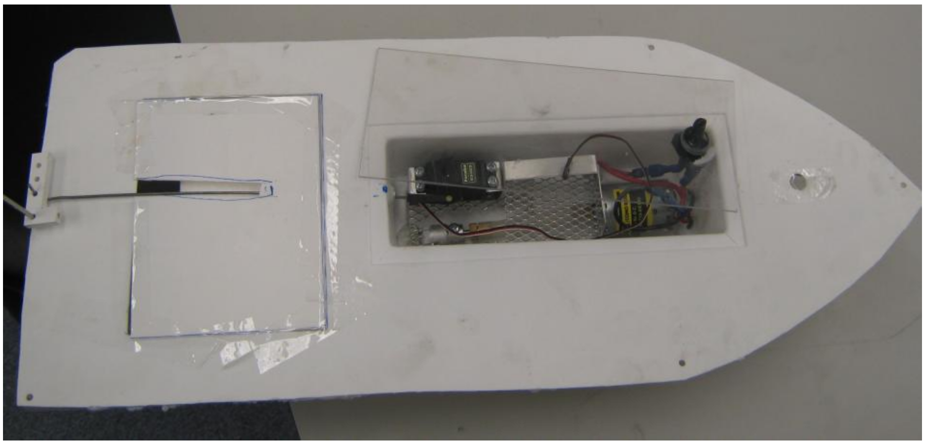

Figure 5.33 Boat made by handcrafting

Discussion

The Figure 5.33 shows a boat made by undergraduate engineering students, which was made by handcrafting and not using CNC machines. It is observed that, since they were unskilled, the boat was not accurate to the CAD models, and not aesthetically pleasing. However, the author who is also unskilled in handcrafting was able to build a similar boat (Figure 5.31 and Figure 5.32) accurate to the CAD models and which was aesthetically pleasing, by using modern manufacturing methods.

Since the university has a CNC milling machine and laser cutting machine, it is suggested that one of the two hulls made by each syndicate be manufactured by CNC milling directly from CAD. Also some of the internal parts of the boat which are at present cut manually using hand tools could be cut by laser cutting. This can give them a better understanding about the modern manufacturing techniques. The other manufacturing methods like rapid prototyping can be avoided as they are very expensive and not readily available.

Chapter 6 Tests and Evaluation

This chapter discusses the testing and evaluation of the model boat produced during this research.

6.1 Testing

The model boat was tested in the university lake. Though the performance of the boat was good it was not as good as expected. It had a promising start but failed to get on to the plane as the power generated by the motor was not sufficient enough that the boat could climb on its bow wave to reach the planing mode (Figure 6.1).

Figure 6.1 Testing of boat in the university lake

Due to unavailability of resources, the exact speed could not be measured. The speed was calculated by measuring the time taken to travel between two points of known distance. The speed of the boat was found to be approximately 2.2 knots. The boat was well balanced and stable throughout the test. The steering of the boat by varying the motor speed was very effective. This test was conducted by supplying 6 volts to each motor. The weight of the boat was 3.1 kg. This compares well with the 3kg predicted during the design process.

To investigate whether planing could be achieved a further test was conducted by supplying 9 volts to each motor which meant adding more batteries. This increased the overall weight to 3.7 kg from the previous 3.1 kg. However, by adding extra batteries the boat did not show any significant improvement mainly due to the increase in weight. There was also a significant voltage drop across the batteries from a nominal 9V to an operating voltage of 4V when the boat was tested in the laboratory water tank. The alkaline batteries were not providing the required power to achieve planing regardless of the different configurations tried. Consequently the alkaline batteries were replaced with NiMH batteries in an attempt to avoid the voltage drop and to give more power output. However, even with the NiMH batteries the boat failed to get onto the plane.

From the test it was observed that the hydrodynamic lift generated was not sufficient enough for the boat to reach the planing mode. This was mainly due to the weight of the boat. Another boat was made using the same mold for the hull but with single motor drive to keep the weight low as shown in Figure 6.2.

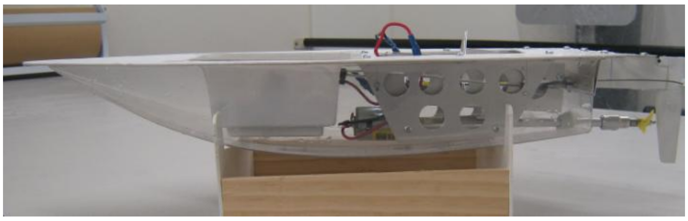

Figure 6.2 Boat with single drive

Since the second boat was single drive, there was the need for a rudder for steering. This boat was supplied with 9 volts, by having 12 batteries connected in series and parallel. The boat weight was 2.2 kg. This boat was also tested in the university lake (Figure 6.3)

Figure 6.3 Testing of single drive boat

The boat performed well but had the same problems, though the weight was reduced and more voltage was supplied to the motor, the boat could still not get onto the plane. The speed was also approximately 2.2 knots, the same as the previous boat. From all these tests it was observed that though the hull was made with the feature of a speed boat, the performance was not achieved.

6.2 Discussion

At the beginning of the project the batteries were not considered a major factor for a successful boat design. However it has been found that they have a significant effect on boat performance. From previous years a fast boat will complete the course of 100m in about 2 minutes. Figure 6.4 shows the race course and Figure 6.5 shows some race day pictures from previous year.

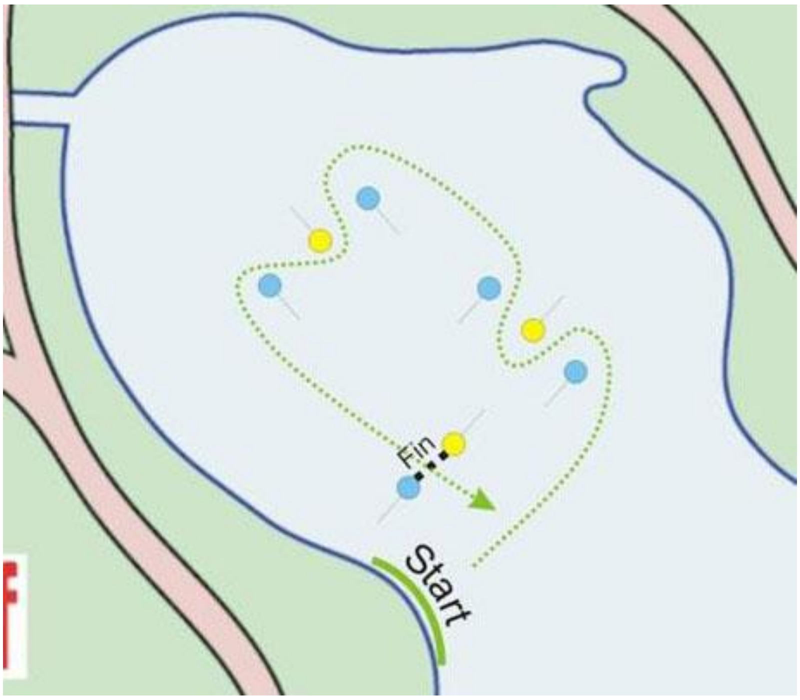

Figure 6.4 Race course

Figure 6.5 Race day pictures

A simple calculation of battery capacity (170Wh) compared to the electrical power to run the two motors (100W) suggested the batteries would easily be able to deliver the required power for 2 minutes. However subsequent battery testing under high current draw, greater than 10Amps showed more than 50% drop in voltage. As power is the product of voltage and current, the electrical power to the motor was under half that expected. This reduction in power by over 50% resulted in the lower than expected boat performance. Interestingly this suggests that if only these batteries and motors are available to students, then hull design is not critical. The key to a 'fast' student boat are optimised battery/motor/propeller system coupled with minimising the weight. Minimising the weight will result in less wetted surface area and therefore lower hull drag. It is also interesting to note that the displacement hull equation predicts a speed of 1.74 knots for the boat. Speed (knots) = 1.34 √ (LWL) which is a nominal guideline for a displacement hull boat. The literature suggests that by adding more power the equation becomes speed (knots) = 1.5 √ (1.7) = 2 knots. This suggests that the 2 propeller model boat is operating slightly better than a displacement hull making just about a semi-displacement hull. Consequently this work predicts that many student boats will have similar speeds, because their power to weight ratio will only produce displacement hull boats. A review of previous boats showed that the smaller, lighter boats were the fastest.

It is clear that even after the laboratory tests that first year students do not know what is an optimal design. Clearly for students to learn how to better predict their boats performance it is suggested that an extra laboratory be developed where the battery/motor/propeller system can be assessed. The objective should be to optimise the power to weight ratio of the drive system. Maybe the focus should be on systems rather than individual components.

Chapter 7 Conclusions and Recommendations

7.1 Conclusion

The model boat building project gives the first year students good exposure to soft skills and some hard skills required by an engineer. The skills learnt during this project give them a good exposure to real life problems faced by engineers which are not available from classroom teaching. Since the whole manufacturing and assembling of the boat are done by students, they get to learn about the manufacturing techniques and get good hands on experience with basic tools and machinery used in industries.

The model boat building is a complex and interesting project, since these boats are tested on race day students get motivated instead of just focussing on getting it done. The laboratory experiments and background research by the students give them knowledge about the critical elements in fast boats. Through laboratory experiments they learn the characteristics of DC motors, propellers and various hull shapes. The exposure to a CAD package in the very first year acts as a foundation to design packages, which is beneficial for their further years of study.

For this research, a review of fast boat hull shapes were carried out which led to the development of a shallow-v hull. The hull was designed in the Solidworks, considering the boat would plane if sufficient propulsive force is available. The mold for the hull was manufactured from MDF, machined using a CNC milling machine directly from the CAD model. The internal parts of the boat were produced by laser cutting. The rapid prototyping methods which can be used to make the mold were not employed as it is very expensive compared to the CNC milling.

The boat manufactured weighed 3.1kg which was close to the 3kg weight predicted during the design process. This boat made by advanced manufacturing methods had a good finishing, and was accurate to the CAD model. However, while testing in the university lake, the boat failed to get onto the plane. This was due to the high voltage drop across the batteries. The voltage drop was measured to be more than 50%. Further tests carried out by adding more batteries too could not show any significant difference. This was because by adding more batteries, the boat's weight also increased. This increase in weight increased the wet surface area which has a direct impact on hull drag.

7.2 Recommendations

Future development of model boat requires more research into the following areas:

Battery modelling

Model boat design is a very complex subject requiring a balance between motor performance, batteries, propellers, hull design and weight. Adding more batteries gives the boat more power but at the same time increases the boat weight, which increases the wet surface area and hull drag. So a further study should be conducted to find the optimum design. The aim would be to predict boat speed from simulating different boat configurations. The first year students could then be shown how professional engineers would design a boat and predict its performance before any prototypes are built. This might be undertaken using for example MATLAB and simulation packages.

Resistance

A further study about the drag resistance caused by different hull shapes at different velocities and trim angle has to be undertaken. By knowing the drag force, the power needed by the boat to overcome the friction could be calculated.

CAE

Advanced computer-aided engineering methods which might predict performance are beyond the abilities of first year students. This eliminates the CAE element of the modern advanced product development methodologies for the boat project. Consequently the only areas that could be introduced directly into the boat project are CAD and some CAM. It is not suggested that the hand skills be removed from the project because it is very useful for engineering students to understand how components are made. However the inclusion of some laser cutting or CNC of one hull is achievable in the university and would help students understand modern methods.

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Appendix 1: ENGG180 Project Rules

- Each Syndicate must design and construct 2 boats. These MUST be 'ready-to-race' in the week prior to race day – there will be no provision for last minute finishing or running repairs. Each boat should be fully functional (no interchanging parts – other than the receiver pack – between boats).
- Failure to follow the rules outlined here may result in disqualification from the race.
- The judge's word is final.

Boat Specifications

1. Total boat width of either boat may not be greater than 450mm.
2. Total boat length of either boat may not exceed 700mm (including rudder).
3. The boat hull must be fashioned from clear plastic (PETG). The hull and deck must be glued together (around the entire edge).
4. Decks must be flat with the water tight compartment formed from the same sheet (i.e. the deck and the water tight compartment is one piece).
5. 15% of each hull **<u>VOLUME</u>** must contain expanded polystyrene (as a single piece per hull). (NOTE: includes any outriggers, pontoons etc). A calculated estimate of 15% of the hull volume must be provided before the hull is vacuum formed.
6. Hatch covers must provide full access to the internal workings. Water tight compartments cannot have a 'partial' hatch with the other part permanently glued in place. Hatch covers must be sealed with water proof tape during racing.
7. The receiver and all water sensitive components must be sealed in a waterproof compartment(s) when on the water.
   - Compartments must be moulded using the pre-prepared shapes available in the lab (will be available for inspection/measuring during the labs).
   - Water tight compartments must have a base plate mounted over the 10mm deep sump. The base plate must allow any water that enters to drain easily into the sump.
   - Servo(s) and control gear must be in the SAME compartment.
   - The receiver and all leased items must be installed without adhesives and in such a way that they are easily removed without cutting away any part of the boat to gain access.
   - Servos must be screwed into a piece of 0.9mm thick aluminium sheet; the piece of Aluminium must be fixed to the base plate of the water tight compartment.
8. The polystyrene adhesive provided is only for sticking pieces of polystyrene foam together and holding the required polystyrene foam within the hull; the single-sided tape is only for sealing hatches (i.e. neither can be used as a general construction material).

Constraints

1. Each syndicate has a $340 credit at Brett's Bargain Basement (BBB), for procuring the materials and components to build their boats with. This excludes the Receiver & Transmitter (R/C gear) which will be provided for free. Transmitters must be returned to BBB at the end of each lab session and at the end of each race on race day. Syndicates are responsible for the care of their receiver units as no replacements will be available. No other materials may be used other than what is listed in BBB's 2010 price list.
2. Only the R/C gear provided by the BBB may be used.
3. You are only permitted to use scheduled Lab periods to work on the boats (i.e. no part of the boat shall be taken home).
4. Only the tools provided for the ENGG180 course may be used to fabricate the boats.

Lab conduct

1. A syndicate may buy materials from BBB by submitting an order form (terms and conditions apply as stated on the order form)
2. All syndicate members must be involved. Syndicate managers may not participate in any "hands on activities".

Penalties

1. If a syndicate member is found to break any of the 6 basic rules of tool safety, then the whole syndicate will be given an immediate 10 min stop work order.
2. Infraction of other rules will result in a 5 second time penalty (per offence) at the end of their first race.
3. If a boat is deemed not to be water tight and/or buoyant it will not be allowed to race.
4. Modification of leased items will result in confiscation of the item without recompense.

Appendix 2: Order form

Syndicate:____________________
Requested By:__________________
Order Date:____________________

Brett's Bargain Basement

ORDER FORM

Product Code	Product Description	Height/Thickness	Length	Width	Inside Diameter (ID)	Outside Diameter (OD)	Grams/Unit	Unit of Measure	Unit Price	Conditions
152	Base plate, expanded aluminium	2	208	59	-	-	12.78	each	$1.24	-
98	Base plate, expanded aluminum	2	120	80	-	-	9.98	each	$0.97	-
149	Base plate, expanded aluminum	2	120	120	-	-	14.89	each	$1.46	-
139	Flat bar, 12mm x 3mm aluminium	3	200	12	-	-	20.44	each	$0.22	-
06	Foam block, 10mm thick HD polystyrene	10	545	195	-	-	22.50	each	$0.51	-
07	Foam block, 20mm thick HD polystyrene	20	545	195	-	-	45.00	each	$0.98	-
146	Foam block, 90mm thick HD polystyrene	90	545	195	-	-	202.50	each	$4.09	-
19	GIB compound, 1.5kg (white)	-	-	-	-	-	1500.00	each	$4.50	-
95	GIB compound, 350g (coloured)	-	-	-	-	-	350.00	each	$2.58	-
138	Rod, ¼" dia. aluminium	-	305	-	-	¼"	6.57	each	$0.10	-
107	Rod, ¼" dia. stainless steel	-	400	-	-	¼"	25.64	each	$0.67	-
129	Sheet, 0.9mm thick aluminium	0.9	300	200	-	-	142.39	each	$1.25	-
130	Sheet, 0.9mm thick aluminium	0.9	300	50	-	-	35.75	each	$0.28	-
112	Sheet, 1.5mm thick PETG, transparent	1.5	755	455	-	-	630.00	each	$9.00	-
02	Sheet, 1.5mm thick TPS, white	1.5	755	455	-	-	538.00	each	$4.90	-
114	Sheet, 6mm thick PVC, white	6	200	50	-	-	78.30	each	$1.07	-
128	Tube, ¼" OD aluminium	-	200	-	⅛"	¼"	17.00	each	$2.48	-
127	Tube, ¼" OD nylon	-	300	-	[illegible]	¼"	1.42	each	$0.39	-
108	Tube, ⅜" OD aluminium	-	300	-	7.7	⅜"	19.73	each	$0.54	-
126	Wire rope, 1.5mm dia. stainless steel	-	400	-	-	1.5	3.72	each	$0.68	-
63	Drill bit, 1.0mm	-	-	-	-	-		each	$1.27	-
64	Drill bit, 1.5mm	-	-	-	-	-		each	$1.14	-
65	Drill bit, 2.0mm	-	-	-	-	-		each	$1.03	-
66	Drill bit, 2.5mm	-	-	-	-	-		each	$1.02	-
67	Drill bit, 3.0mm	-	-	-	-	-		each	$0.99	-
68	Drill bit, 3.2mm	-	-	-	-	-		each	$0.79	-
69	Sand Paper,120 Grit	-	140	115	-	-		1/4 sheet	$0.21	-
137	Battery (C-size)	-	50	-	-	25	68.66	each	$1.53	NR
133	BLUE Crimp Connector, Butt Splice	-	-	-	-	-	1.28	each	$0.32	-
134	BLUE Crimp Connector, Female Spade (6.3 x 0.8)	-	-	-	-	-	1.28	each	$0.42	-
135	BLUE Crimp Connector, M4 Ring	-	-	-	-	-	0.75	each	$0.20	-
132	BLUE Crimp Connector, Male Spade (6.3 x 0.8)	-	-	-	-	-	0.95	each	$0.31	-
136	Electrical Cable, 2-core 1.5mm², twisted pair	-	800	-	-	-	46.57	each	$1.40	-
45	Kwick Link (to fit 2-56 thread), with safety lock	-	-	-	-	-	0.97	each	$2.45	-
57	Microswicth	-	-	-	-	-	7.95	each	$3.81	Lease*
131	Motor, 3-pole RE-540, 3...9V	-	-	-	-	-	158.64	each	$12.50	Lease
44	Push Rod (2-56 thread one end)	-	12"	-	-	0.072"	0.52	each	$1.16	-
77	Push rod boot, flexible	-	-	-	-	-	0.83	each	$8.00	-
43	Servo Horn, Type "G"	-	-	-	-	45	5.19	each	$1.40	-
42	Servo, Standard	-	-	-	-	-	35.91	each	$31.50	Lease*
150	Sponge Strip, rectangular, double sided adhesive,	12	100	15	-	-	2.80	each	$0.61	-
148	Sponge Strip, round, EPDM	-	100	-	-	9	2.74	each	$0.61	-
124	Spring	-	6.2	-	4.27	5.39	0.13	each	$0.50	-
52	Terminal block, 5-way	-	-	-	-	-	6.65	each	$0.58	-
58	Toggle switch with water proof cover	-	-	-	-	-	10.34	each	$7.81	Lease*
38	Adhesive, general purpose, clear, 30g bottle	-	-	-	-	-		g	$5.00	-
37	Cable tie, 2.5mm x 100mm, nylon	-	-	-	-	-	0.29	each	$0.09	-
125	Cable tie, releasable, 300mm, nylon	-	-	-	-	-	2.83	each	$0.15	-
24	Cap screw, M3 x 6mm, 304 stainless	9	-	-	-	-	0.69	each	$0.25	-
143	Epoxy Putty, 7.5g	-	-	-	-	-	7.50	each	$1.25	-
121	Hex head set screw, M4 x 10mm, ZP	13	-	-	-	-	1.58	each	$0.07	-
122	Hex head set screw, M4 x 16mm, ZP	19	-	-	-	-	1.98	each	$0.08	-
151	Hex head set screw, M4 x 25mm, ZP	28	-	-	-	-	2.18	each	$0.10	-
36	Hinge, 25mm, stainless Steel	4	26	40	-	-	8.13	each	$2.50	-
115	Nut, full M4, ZP	3.1	-	-	M4	-	0.68	each	$0.03	-
140	Nut, nylock M4, ZP	4.8	-	-	M4	-	8.62	each	$0.10	-
116	Nut, wing M4, ZP	9.9	-	21.3	M4	-	3.34	each	$0.19	-
142	P-Clip, ¼" fixed daimeter	-	-	-	-	-	0.41	each	$0.21	-
123	Socket set screw, M4 x 6mm, blackened steel	6	-	-	-	-	0.31	each	$0.22	-
141	Spacer, M4 x 10, brass	18	-	-	-	-	3.35	each	$0.56	-
118	Thread forming screw, M4 x 6mm, ZP	9.2	-	-	-	-	1.21	each	$0.14	-
117	Washer, standard M4, nylon	.8	-	-	4.4	8.8	0.04	each	$0.09	-
120	Washer, standard M4, ZP	.8	-	-	4.4	8.8	0.26	each	$0.02	-

100	2-Blade water propeller (50mm dia. x 1.2 pitch)	-	-	-	3/16"	50	2.54	each	$4.50	Lease
101	2-Blade water propeller (50mm dia. x 1.4 pitch)	-	-	-	3/16"	50	3.44	each	$4.50	Lease
102	2-Blade water propeller (50mm dia. x 2.0 pitch)	-	-	-	3/16"	50	2.58	each	$4.50	Lease
113	Bearing	-	-	-	1/8" x 3/8"	-	11.14	each	$5.00	Lease, NR
144	Bush. 3/16" OD x 1/8" ID brass	-	25	-	1/8"	3/[illegible]"	2.03	each	$0.10	-
106	Collar, 1/8" ID	-	-	-	1/8"	-	1.24	each	$1.16	Lease, NR
105	Dog drive, 3/[illegible]" ID	-	-	-	3/16"	-	3.09	each	$5.50	Lease, NR
147	Drive shaft assembly (leased parts)	-	-	-	-	-	41.57	set	$27.00	Lease
109	Tube, 1/4" ID silicon rubber	-	100	-	1/4"	11	5.96	each	$1.08	-
103	Universal joint insert, 3.2mm bore	-	-	-	3.2	-	7.48	each	$9.50	Lease, NR
145	Servo screw, replacement	-	-	-	-	-		each	$0.50	-
31	Socket set screw, M3 x 3mm, blackened steel	-	-	-	-	-		each	$0.13	-

Appendix 3: Safe Operating Practice for Tool Use

DONOT use tools if overly tired or under the influence of drugs or alcohol.

KEEP aware of others around you as well as the job at hand.

WALK; DONOT run in the Laboratory.

DONOT interrupt someone using a power tool; **WAIT** for them to finish.

CHOOSE the right tool for the job.

- **DONOT** use a knife where a screwdriver is required is an example.

INSPECT tools before use.

- **DONOT** use damaged tools; **REPORT** damaged tools and power cords to the Technician.
- **ENSURE** power tools are switched off before plugging into the power supply.

USE tools correctly.

- **TUCK IN** loose clothing and **TIE-BACK** long hair.
- **PRACTICE** with the tool first.
- **SECURE** work with a vice or clamp; **DONOT** hold work by hand.
- **POSITION** yourself so that you are well balanced with solid footing, and are not overreaching.
- **DONOT** force a tool beyond its capacity.
- **FOLLOW** the specific Standard Operating Procedures (SOP) of a power tool in addition to this Safe Operating Practice.
- **DONOT** modify or jury rig tools and equipment.
- **ASK** a Technician for help if you are unsure how to use a tool.

USE Personal Protective Equipment (PPE).

- **WEAR** safety glasses and appropriate footwear at all times.
- **WEAR** ear plugs/muffs when using power tools for extended periods of time.
- **WEAR** cut-resistant gloves when handling sharp or abrasive materials.
- **WEAR** a dust mask when sanding.
- **WEAR** gloves and a plastic apron (or lab coat) when using adhesives.

KEEP the work area safe and tidy.

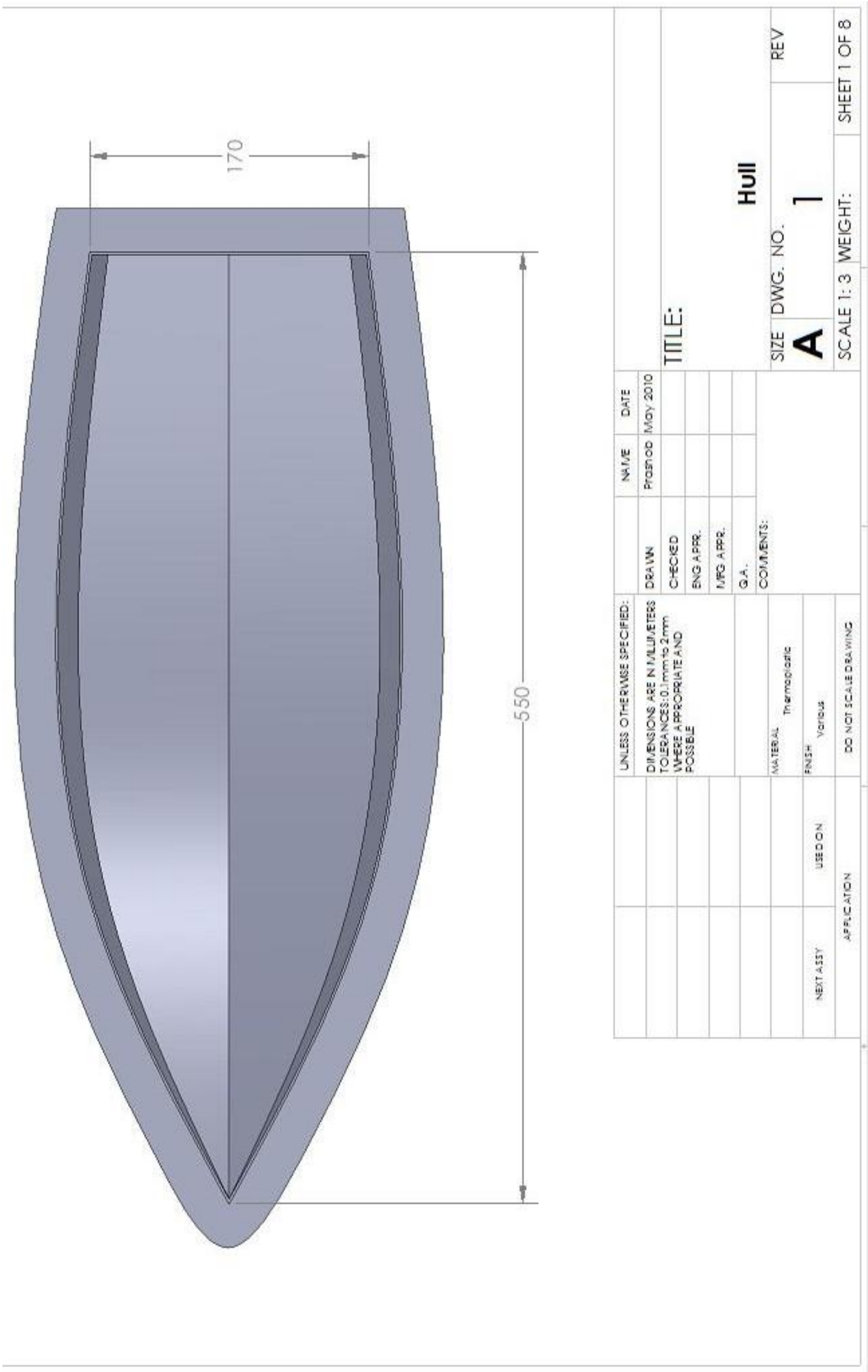
- **ENSURE** work area is uncluttered.
- **ENSURE** floor is safe and tidy; **REMOVE** off cuts from the floor as soon as possible.
- **ENSURE** power cords do not present a trip hazard and are free from others work.
- **USE** cutting boards or a tool bench for cutting and drilling; **DONOT** directly use Laboratory benches.
- **CLEAN** work area when finished and before you leave for the day.

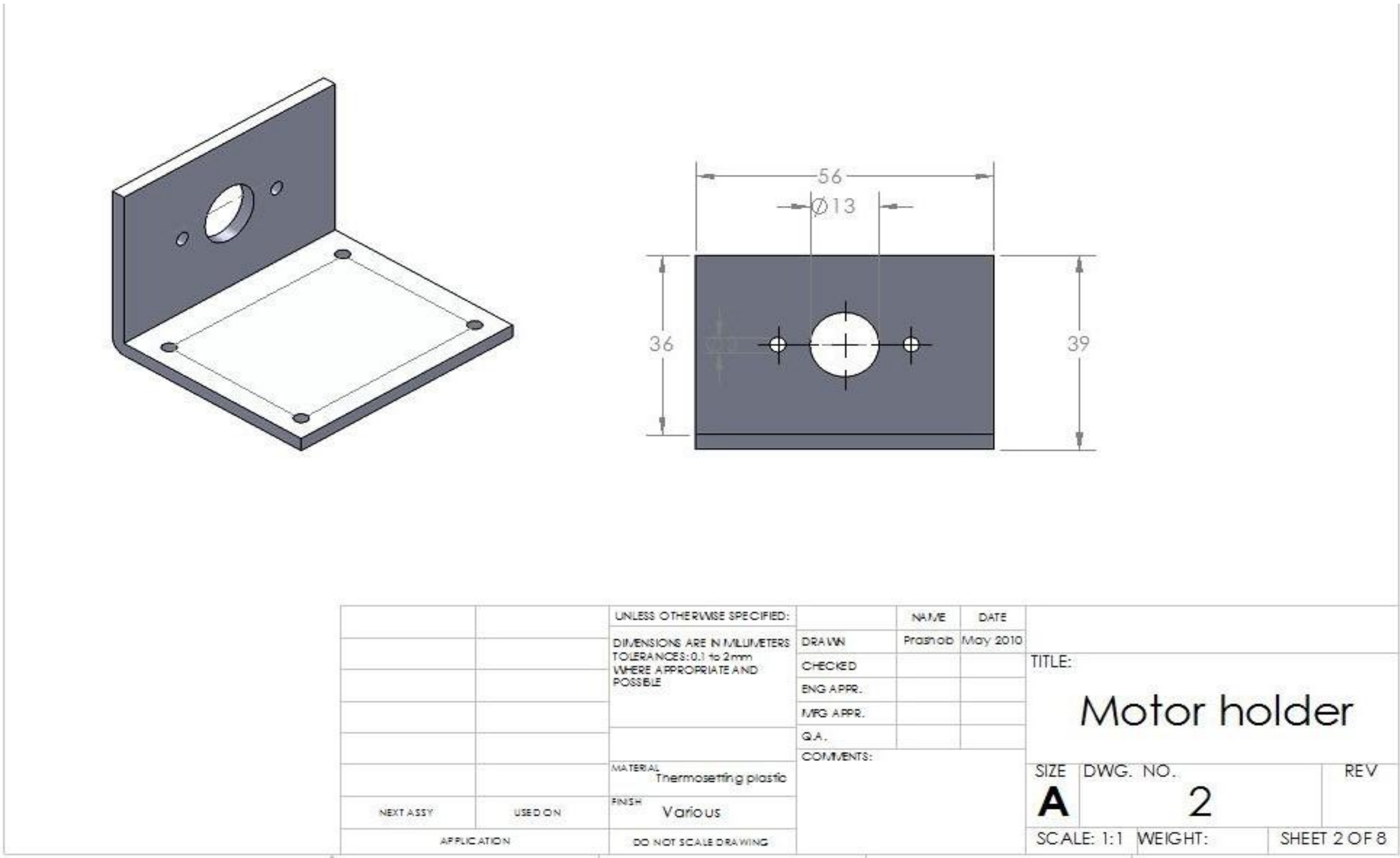
CARRY and **STORE** tools safely.

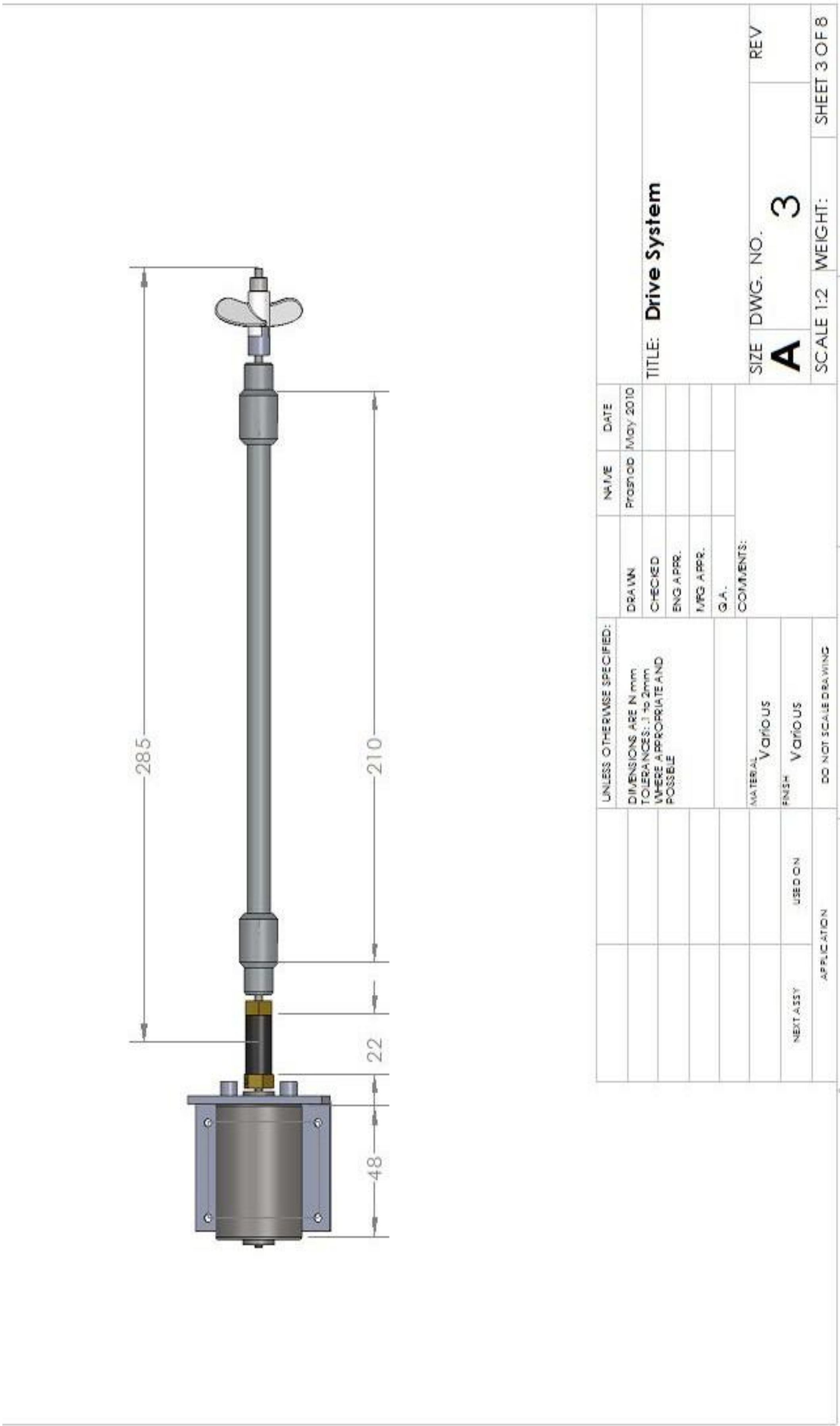
INSPECT tools for damage before storing tools; **REPORT** damaged tools and power cords to the Technician.

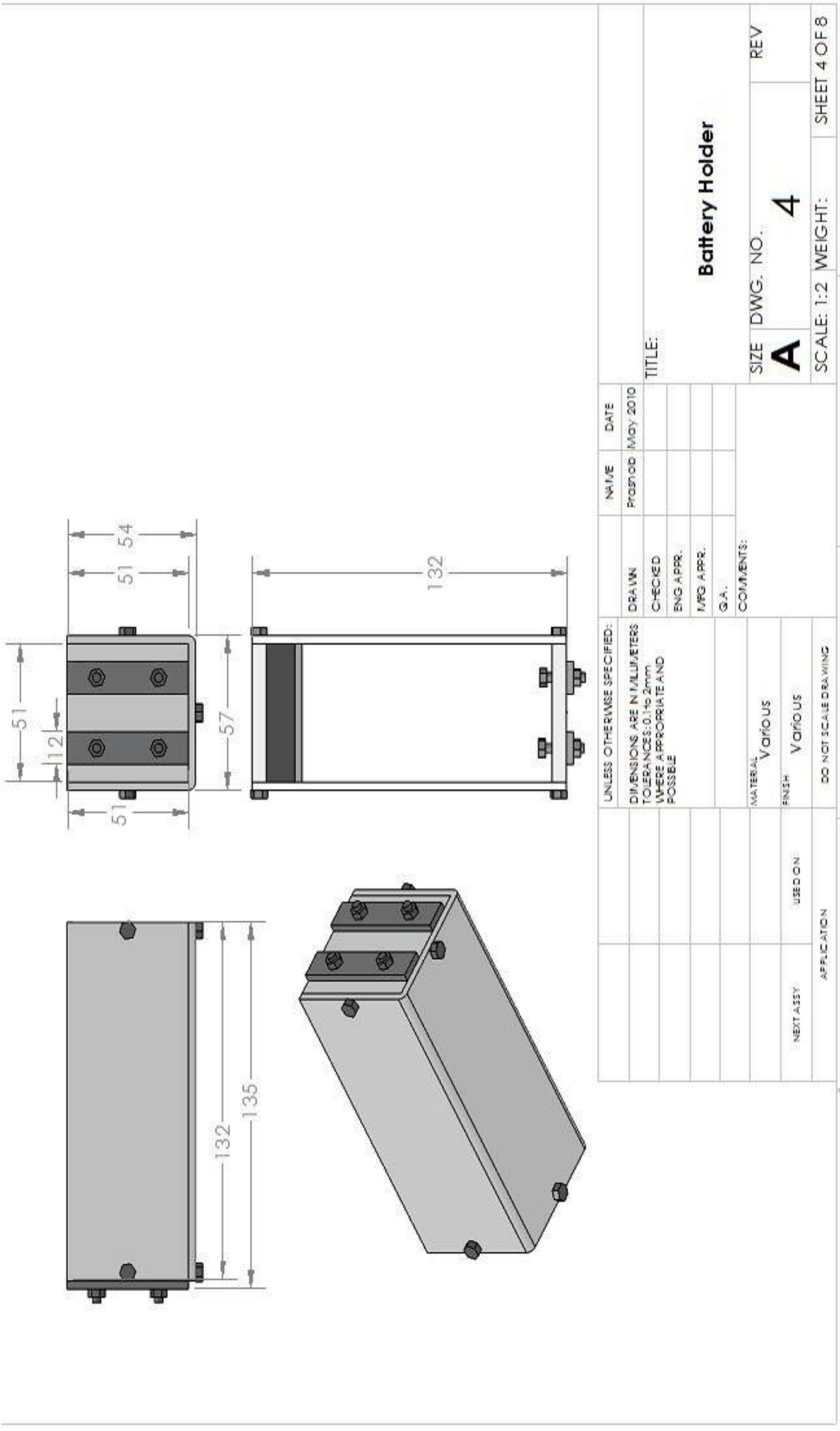
- **RETURN** tools to their correct place/draw when the task is finished and before you leave for the day.
- **RETRACT** blades when not in use.

Appendix 4: Drawings

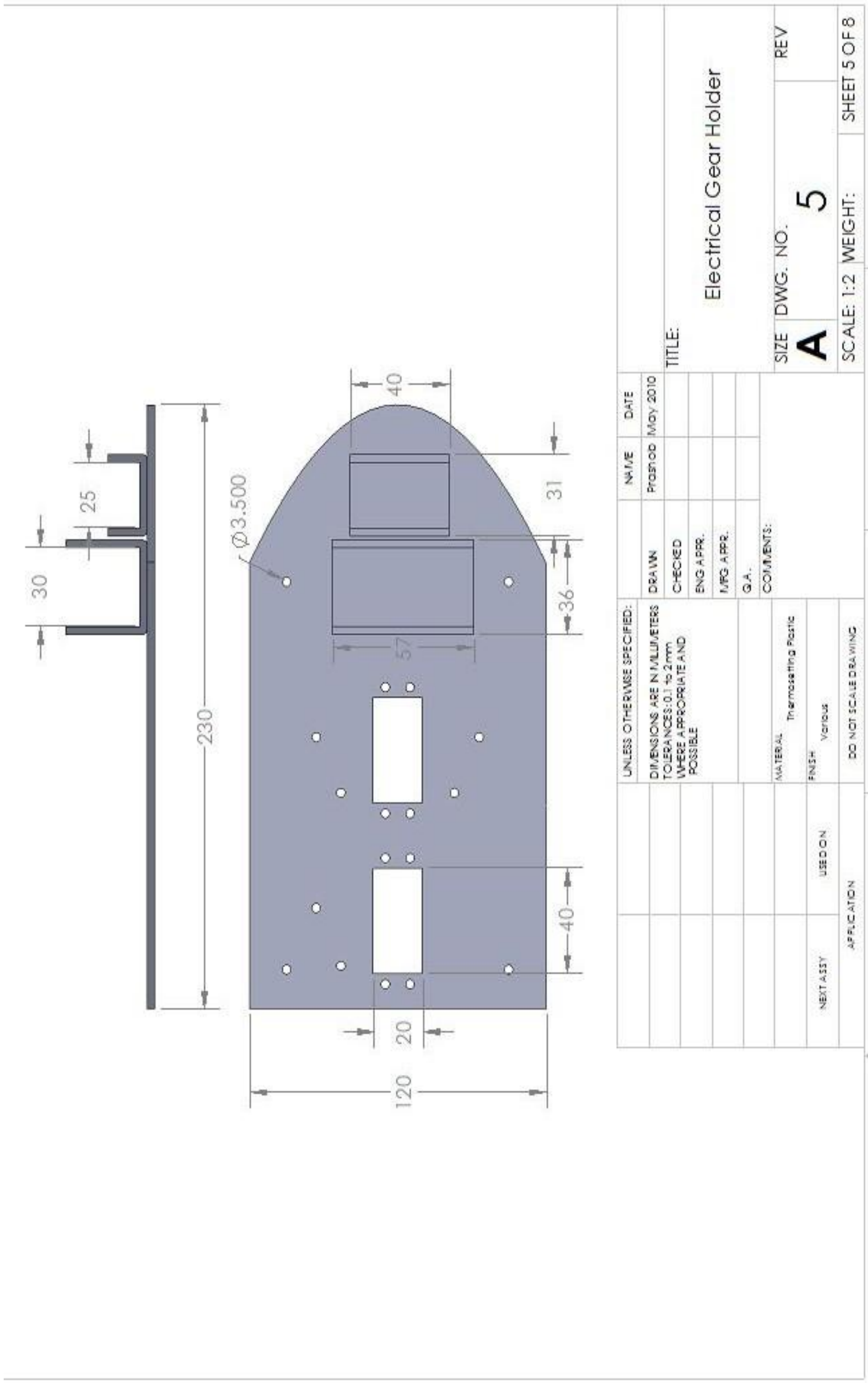


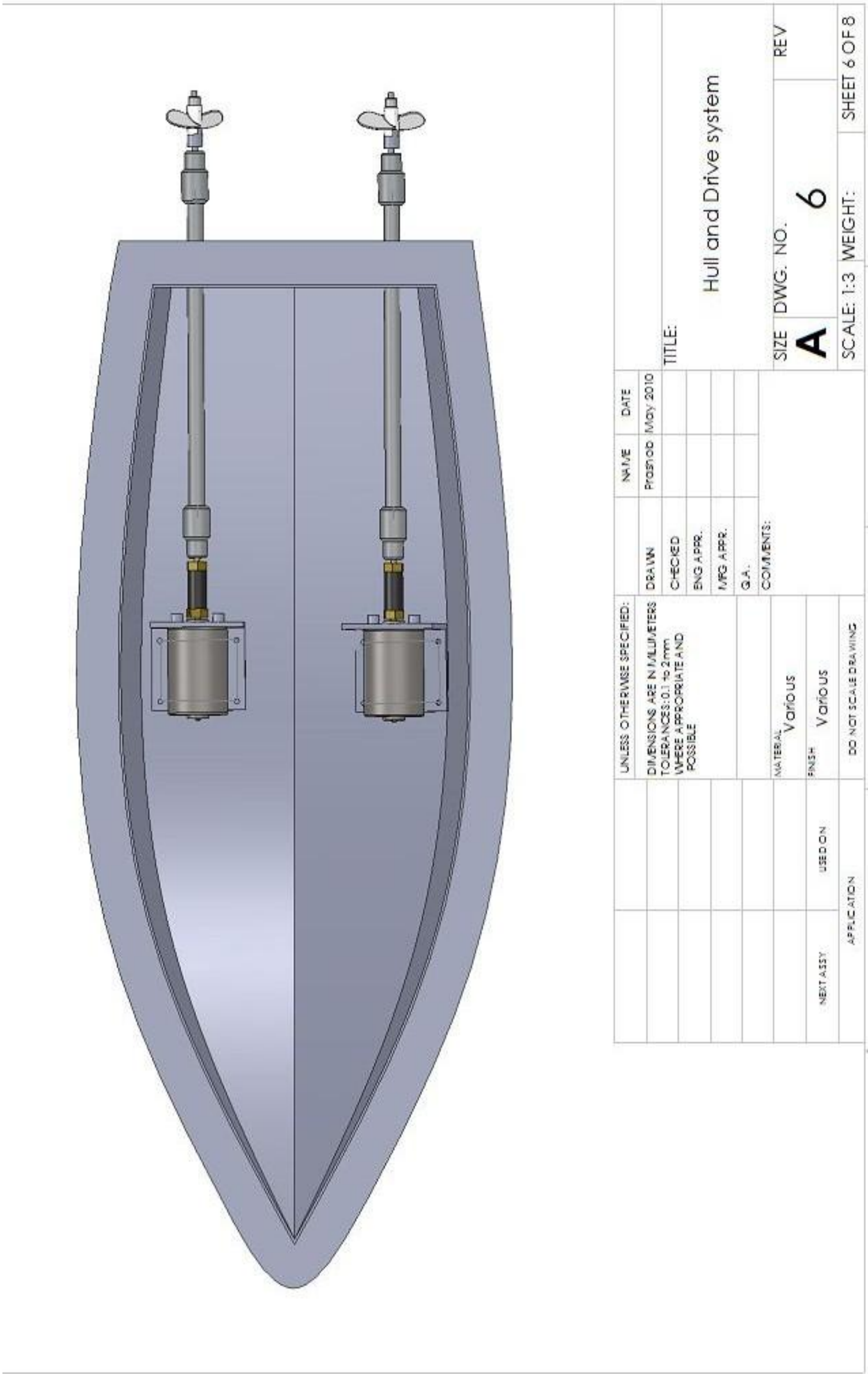

56
Ø13
36
39
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES: 0.1 to 2mm
WHERE APPROPRIATE AND POSSIBLE
MATERIAL Thermosetting plastic
FINISH Various
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN Prasnab May 2010
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Motor holder
SIZE A
DWG. NO. 2
REV
SCALE: 1:1
WEIGHT:
SHEET 2 OF 8


285
48
22
210
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN mm
TOLERANCES: .1 to 2mm
WHERE APPROPRIATE AND
POSSIBLE
NAME
DATE
DRAWN
Prasnab
May 2010
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
Various
FINISH
Various
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
TITLE: Drive System
SIZE
A
DWG. NO.
3
REV
SCALE 1:2
WEIGHT:
SHEET 3 OF 8

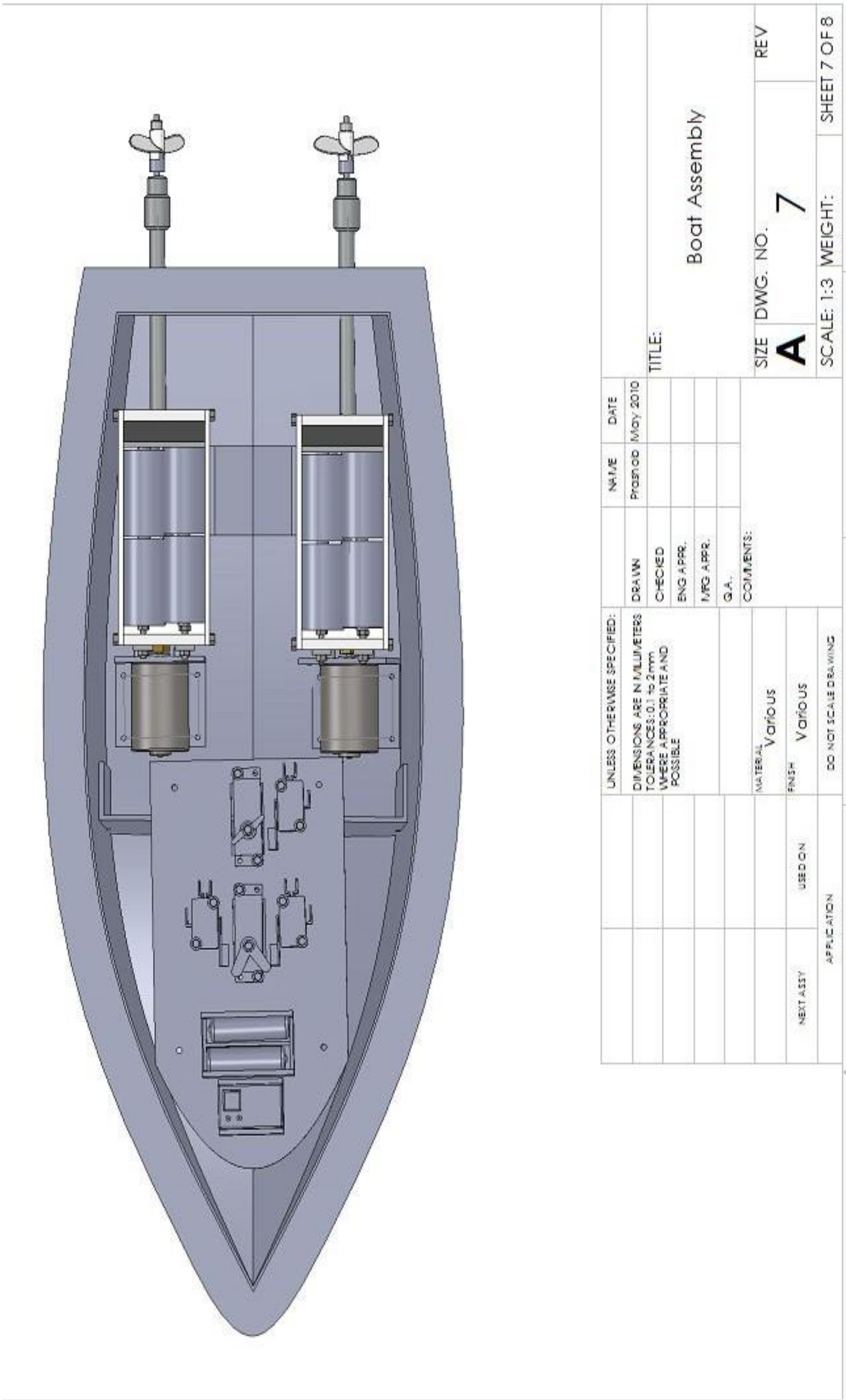


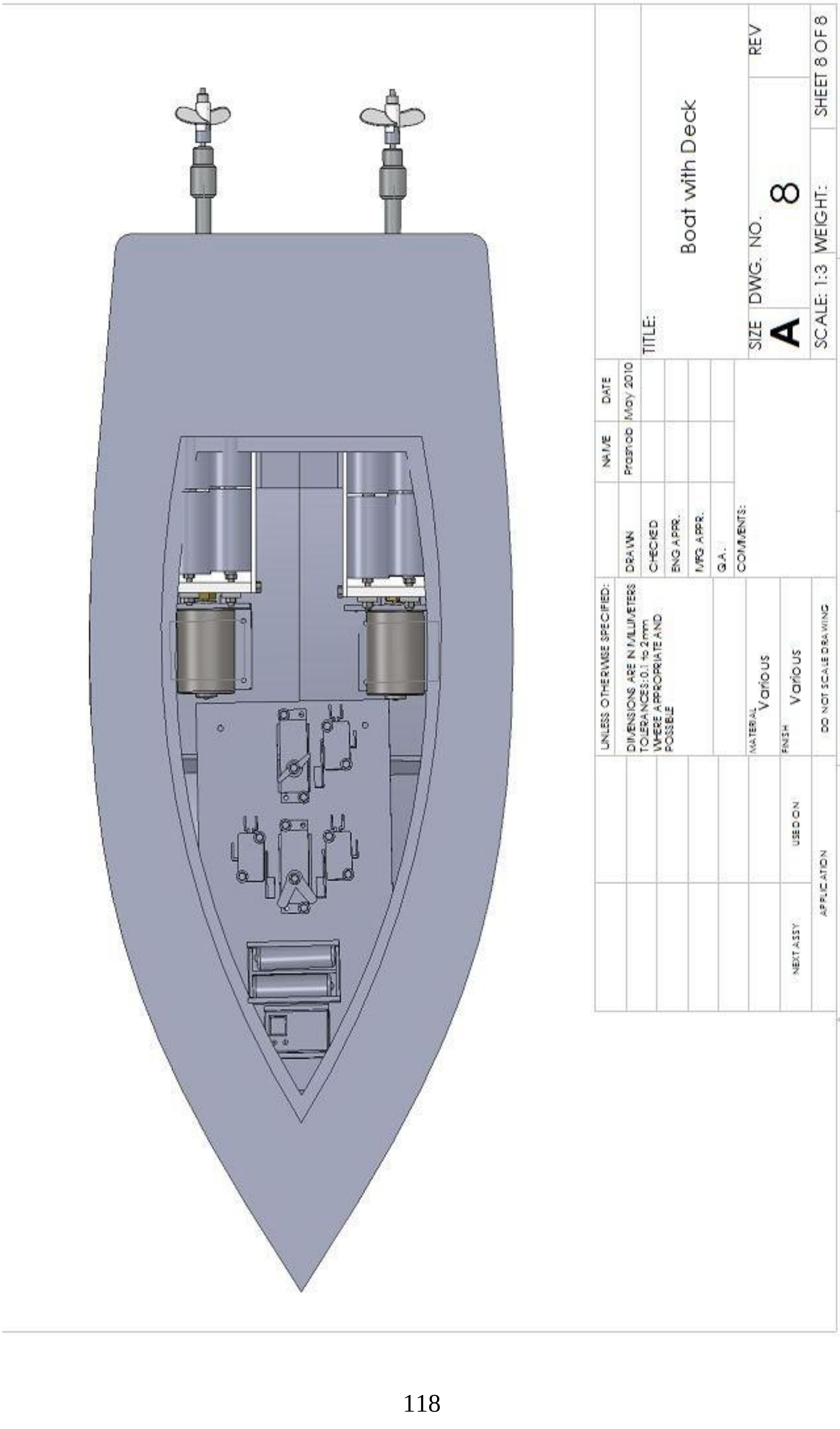
54
51
51
12
51
57
132
132
135
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES: 0.1 to 2mm
WHERE APPROPRIATE AND POSSIBLE
NAME
DATE
DRAWN
May 2010
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
Various
FINISH
Various
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
TITLE:
Battery Holder
SIZE
A
DWG. NO.
4
REV
SCALE: 1:2
WEIGHT:
SHEET 4 OF 8


Electrical Gear Holder
TITLE:
SIZE
A
DWG. NO.
5
REV
SCALE: 1:2
WEIGHT:
SHEET 5 OF 8
NAME
DATE
DRAWN
Prasnna
May 2010
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES: 0.1 to 2 mm
WHERE APPROPRIATE AND POSSIBLE
MATERIAL
Thermosetting Plastic
FINISH
Various
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
40
31
36
57
Ø3.500
230
25
30
40
20
120



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES: 0.1 to 2mm
WHERE APPROPRIATE AND POSSIBLE
NAME
DATE
DRAWN
Prasnab
May 2010
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
Various
FINISH
Various
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
TITLE:
Hull and Drive system
SIZE
A
DWG. NO.
6
REV
SCALE: 1:3
WEIGHT:
SHEET 6 OF 8


UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES: 0.1 to 2mm
WHERE APPROPRIATE AND POSSIBLE
NAME
DATE
DRAWN
May 2010
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
Various
FINISH
Various
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
TITLE:
Boat Assembly
SIZE
A
DWG. NO.
7
REV
SCALE: 1:3
WEIGHT:
SHEET 7 OF 8


UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:0.1 to 2mm
WHERE APPROPRIATE AND
POSSIBLE
NAME
DATE
DRAWN
Prasnab
May 2010
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Boat with Deck
SIZE
A
DWG. NO.
8
REV
SCALE: 1:3
WEIGHT:
SHEET 8 OF 8
MATERIAL
Various
FINISH
Various
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION