CONSTRUCTION OF AN AUV PLATFORM: ELECTRONICS

Summer Final Report

by

C. Sherece Wade

OCE MFP 1999: Marine Field Project
Submitted to Dr. A. Zborowski

July 22, 1999
## Contents

EXECUTIVE SUMMARY ................................................................. 1

1.0 INTRODUCTION ....................................................................... 2
  1.1 Purpose of Project............................................................... 2
  1.2 Background................................................................. 3
  1.3 Sources of Information..................................................... 6

2.0 DESIGN PROCEDURE............................................................. 6
  2.1 Timeline........................................................................ 6
  2.2 Electronics................................................................. 7
  2.3 Budget....................................................................... 8

3.0 RESULTS ............................................................................ 8
  3.1 Timeline........................................................................ 8
  3.2 Electronics................................................................. 9
  3.3 Budget..................................................................... 10

4.0 DISCUSSION................................................................. 10

5.0 CONCLUSION................................................................. 12

6.0 RECOMMENDATIONS.......................................................... 13

7.0 WORKS CITED................................................................. 14

APPENDIX: DESIGN OF AN AUV PLATFORM................................. 15
List of Figures

Figure 1. RoboTuna.................................................................4
Figure 2. AQUA EXPLORER 1000...........................................4
Figure 3. MAUVE...............................................................5
Executive Summary

Ocean engineers have been extensively designing and constructing vehicles to be used underwater for over 30 years. Underwater submersibles serve various purposes although they are generally the same shape: cylindrical. In this project a spherical autonomous underwater vehicle was designed to prove whether a cylindrical AUV was the only shape possible. It’s never been done before and therefore this project is a first of its kind. A 386 microprocessor was obtained to control a 13-inch diameter glass sphere and its electrical components.

After working on the AUV for a number of months the conclusion was reached that the electronics part of the project couldn’t be done. Although various sources of help were appealed to, not enough knowledge was available in the allotted time frame to fully understand all that was necessary to program the microprocessor and to control the motors that moved the submersible. The planned budget and the timeline were also not followed because of unanticipated problems. In the end the project proved to be too much for a two-person undergraduate team to do in only three months.

For future projects it is recommended to do a project on a subject that currently exists. Therefore research can be done on the subject and the team members will have references to help guide them through the project.
1.0 Introduction

1.1 Purpose of Project

In the fields of oceanography and ocean engineering the need for continuous study of the underwater world is great. Therefore engineers are constantly developing new machines that can fulfill this need. The purpose of this project is to design and construct an autonomous underwater vehicle (AUV). An AUV is a machine used underwater for research purposes such as observation and data collection. The term "autonomous" refers to the submersible's ability to move about and control itself without the aid of remote control. For this project the AUV is a glass sphere with an inside diameter of thirteen inches that houses all the necessary electrical components, including the motors and the main microprocessor, as well as a completely autonomous, battery-operated mechanical system.

Most AUVs come in the same general shape: long, cylindrical bodies that hinder their maneuverability. After some calculations it was found that a sphere could withstand at least as much pressure as a cylinder, but has better maneuverability because of its shape. Although information about spherical AUVs is scarce, the purpose of the project is to construct one and prove whether it is possible or not. The overall objective of the AUV for this project is to move across a body of water, changing direction while in motion, without any remote controls or other outside aid.

If successful, additional electronics could be added to the AUV to enhance its objectives. When complete the AUV would be capable of operation in small enclosed environments, such as caves and shipwrecks, while navigating itself and videotaping its surroundings using a GPS navigational system and a video camera. Oceanographic
instrumentation could be added for sampling and data collection (see Appendix, section 1.2).

1.2 Background

Although there are a number of ways of exploring the ocean, unmanned submersibles hold a number of advantages over manned submersibles. A few examples include: the time and cost efficiency of building an unmanned submersible, the elimination of risk of injury to people, and the decrease in size of the submersible which increases the options of where the it can go (Geyer, 1977). Autonomous underwater vehicles have further advantages over remotely operated vehicles, such as the increase in depth and/or distance capabilities because of the lack of an attached cable. An AUV can also “think” for itself and therefore does not need someone to control where it goes or what it does: the computer within the AUV controls its speed and direction as well as its objective while submerged.

There are numerous design projects for various AUVs that have taken place throughout the world. Massachusetts Institute of Technology is where the RoboTuna project was developed (see Figure 1). The RoboTuna is an experiment for the optimal control of a flexible hull robotic undersea vehicle propelled by an oscillating foil (1996 Symposium). Using biological systems for inspiration, the RoboTuna has a flexible hydrodynamic body, which is propelled by an oscillating tail foil. A self-optimizing motion controller was developed, based on a genetic algorithm, which uses evolutionary principles to improve how well the fish “swims” (1996 Symposium).
In Japan, an autonomous underwater robot "AQUA EXPLORER 1000" was built to inspect underwater telecommunication cables (see figure 2, right). The AE1000 can find and track buried underwater cables with a cable-tracking sensor and record the view of the seafloor using an on-board VCR (1996 Symposium).
In France, the overall objective of the MAUVE project (Mini Autonomous Underwater Vehicle) was to develop and validate at sea a miniaturized, reconfigurable, mobile and autonomous instrumented vehicle (see Figure 3). Its purpose is to survey coastal waters. Its system operational specifications include a low-cost baseline with multi-instrument capability, easy maintainability and fast new-mission reconfiguration, and multi-vehicle configuration capability (1996 Symposium). Basically this means the MAUVE doesn’t cost much and it’s easy to take care of. Also, it can control numerous instrumentation, can work with other vehicles and is easy to reprogram with new missions.

Figure 3: MAUVE
1.3 Sources of Information

For the electronics part of this project various help was called on. From Superior Modular Products, General Technology Division, Engineering Manager Joe Laccone and Technical Support Supervisor Frank Hosna donated the 386 microprocessor that was to be used in the AUV. They also offered information and suggestions on the use of basic computers and electronics in projects of this type. From the Department of Electrical and Computer Science and Engineering at Florida Tech, electrical engineering graduate student Jamal Hassan contributed greatly to trying to set up the electronics, such as the stepper motors.

2.0 Design Procedure

2.1 Timeline

The proposed timeline for this project was as follows:

Week Ending:

May 21 – 1. Design of the internal gear using AutoCAD

2. Identify local supplier of pressure housing parts

3. Acquire known parts

May 28 – 1. Export internal gear design to MasterCam and mill out the internal gears

2. Construct the control system

3. Start coding and programming the microprocessor to control the various systems of the AUV

June 4 – Cruise Week

June 11 – 1. Construct pressure housing for propulsion and batteries
2. Connect various electrical components to the microprocessor and test to see how well the processor controls each component

June 18 – Build the propulsion tube

June 25 – 1. Construct mounting brackets and begin final assembly

2. Finalize testing of completed AUV and test in pool

2.2 Electronics

The main electrical component of the AUV is the microprocessor, a Trenton Technologies D386SX processor. A microprocessor is a small computer board that contains all the necessary components to function as a computer. The board used in this AUV will be the “brain” of the submersible, controlling how and where it moves. It contains one megabyte of RAM and its dimensions are 7” x 4”. Assembly or a C language could be used to program the board. To power the board a *5V at .5 Amps are required.

The microprocessor will control the two stepper motors that are to be used to control the weight rotation system. A stepper motor is a motor that rotates in steps instead of working in one direction like a regular motor. Once connected to a driver, which in turn is connected to a computer, it can be programmed to rotate by degrees. For example, at 2°/sec, the motor will rotate two degrees every second. In this project the weight rotation system will be controlled by the stepper motors so as the motor rotates the lead weight attached to the internal gear system (see Appendix, section 3.7) the entire AUV will shift direction. One stepper motor will rotate the AUV in the x-direction and the other will control it in the y-direction.
2.3 Budget

To purchase the items necessary for this project $1000 was allotted. The proposed budget was as follows:

1. Propellers ~$50 each x2 $100
2. Propeller Motors ~$30 each x2 $60
3. Raw Materials $300
4. Batteries
   30 Rechargeable C cells ~$220 $220
   30 Rechargeable D cells ~$220 $220
5. Miscellaneous $150

TOTAL $1050

The raw materials are the materials needed to build parts of the AUV, like aluminum for the internal gears and PVC for the housing. The microprocessor, the glass sphere that provides the AUV housing, two stepper motors, and the stepper motor driver are all to be donated and therefore do not need to be taken into account. An estimated total amount for the donated materials is about another $1000.

3.0 Results

3.1 Timeline

There were numerous problems that had to be dealt with throughout the project and as a result the timeline was disregarded completely. The initial design work was done on time, but most of the necessary parts needed to be ordered and they didn’t come in until late. The internal gear was not milled out until the middle of June, construction of the pressure housing began in late June/early July, and coding the
microprocessor proved to be harder than intended and was therefore never done. The glass sphere and the gears weren't ordered until late June, and by mid-July the parts still had not come in.

3.2 Electronics

The original plans for the microprocessor didn't work because the task was much more difficult than originally planned. After consulting with computer experts Joe Laccone and Frank Hosna it was realized that programming the processor was too complicated. Laccone and Hosna both agreed that programming the processor to control multiple motors was too advanced a project. They admitted that they themselves would not have been able to undertake the task, especially in the time frame of this project. The best they said could be done would be to control the motors remotely, which went against the goals of the project.

Similar problems were found when dealing with the electronics. Electronics graduate student Jamal Hassan was perplexed with the job of controlling the stepper motors. The motors had to be connected to a driver, along with other electronic devices, such as a power supply and a clock. Hassan at one point noted that knowledge in digital logic would be required. A major difficulty was reached when trying to connect the driver to the circuit: the wires couldn't be connected to the driver because the driver's connection points were considerably larger than the thickness of the wire.
3.3 Budget

Although the budget limits were not exceeded, numerous unforeseen purchases had to be made, such as the sphere. The glass sphere originally was supposed to have been donated, but because of communication problems it had to be purchased from another company. A breakdown of the final budget is as follows:

1. propellers x2 $91
2. glass sphere x1 $160
3. hose clamps for sphere x6 $30
4. gears x8 $109
5. raw materials $150
6. Film x4 $16
7. 6V battery x1 $4
8. Miscellaneous $110

TOTAL $720

4.0 Discussion

This project was very complex. Many unexpected problems were faced and although some of them were dealt with, some of them could not be solved. The major problems that were easily dealt with were the ones concerning the materials and the budget. The sphere had to be purchased because of lack of communication within the company that originally promised the sphere. In the end a sphere had to be purchased from another company. The company reduced the price of the sphere because of the nature of the project, so purchasing the sphere didn't cause any budget problems. The reason why there was so much extra money within the budget is because the prices for
the known materials were all guessed, so many of the amounts requested
overcompensated for the actual amount of the item. For instance, $440 was requested
for purchase of 50 batteries, but in the end only $4 was needed for one battery.
Therefore $336 was left to use towards other materials. By the same token, $300 was
requested for raw materials such as aluminum plates and PVC piping. The final budget
shows that only half of that was actually necessary, leaving $150 to purchase other
items.

A major problem that couldn't be solved involved the electronics. It was
impossible to get the necessary electronics programmed, connected, and integrated into
the sphere in the allotted time. Experts in both the computer and the electronics fields all
agreed that two undergraduate students could not perform the essential tasks because
they didn't know enough about electronics and computers. Computer engineers Joe
Laccone and Frank Hosna at one point suggested hooking up a remotely controlled
system, but since the purpose of the project was to construct an autonomous vehicle, the
idea couldn't be applied. Otherwise, not enough information about programming a
computer board was known, and not enough time was available to learn. Electronics
graduate student Jamal Hassan also said that more knowledge was needed. While
trying to set up the stepper motors to numerous electrical components (that were later
supposed to all be replaced by the microprocessor) he said that digital logic would
explain how everything worked. Since the team members didn't know digital logic, the
project couldn't be finished.

Another unanticipated problem with the project was the timeline. Although the
amount of time needed to put everything together was taken into account, the time
needed to order items was not. None of the orders were placed until late June and each
company needed about a week to deliver the items. Two weeks after everything was

11
ordered it was discovered that none of the orders went through and therefore had to be reordered, adding another week to the needed time. So final construction and testing on the sphere couldn't take place because the sphere hadn't arrived by the second week of July. Problems with the electronics led to the lack of work getting done on time. Although programming was supposed to be finished by the second week of June, it was never done because not enough knowledge or time was available to program the microprocessor. Likewise, the electronics weren't done by the second week of June because it was found that the electronics couldn't be done.

5.0 Conclusion

The electronics of this project were more involved than expected. Not enough information was known to obtain the wanted goals. Two computer experts confirmed that the project was too difficult for a two-person undergraduate team, and an electronics graduate student suggested that more knowledge be obtained before attempting to do this extensive of an electronics project.

It is also troublesome to plan for a project this extensive. The original timeline was completely changed due to circumstances beyond control. Materials that needed to be ordered were not factored into the timeline. Planning for the budget was difficult as well. The amount of the allotted budget was not exceeded only by overcompensating for the materials that were known to be needed. Also, outside donations and discounts helped with the costs.

In conclusion, based on the project goal of proving whether it is possible to build a spherical AUV, it is not possible for two undergraduate students who don't have extensive knowledge in computers and electronics to program and construct the
electronics aspect of an autonomous underwater vehicle. It is also difficult to plan for such an intricate project. There are materials that need to be ordered and purchased that it's hard to prepare for.

6.0 Recommendations

The first recommendation is to ensure that the topic chosen is a subject that the team members are familiar with. It cuts out time because the project becomes more complicated if the team members have to learn about the subject after the design has started. Choosing a topic where an entire class has to be taken to understand a certain aspect of the project is strongly discouraged.

Another recommendation is to do extensive research on the project topic. Read about what other researchers have done to get similar projects done. It's easier to plan for things if it's known what other people needed for the same or similar projects. This way a sensible timeline can be derived based on the time that other scientists needed, and a suitable budget can be requested based on the known prices of the materials required.
7.0 Works Cited


APPENDIX: DESIGN OF AN AUV PLATFORM
DESIGN OF AN AUV PLATFORM

Spring Final Report

OCE4541 OE Systems Design
Submitted to Dr. A. Zborowski

April 29, 1999

Project team members:

Mechanical Systems- Chris Lathan
Electronic Systems- Sherece Wade
Table Of Contents

Executive Summary ............................................................................................................. 3
1.0 Objective ....................................................................................................................... 4
  1.1 Statement ..................................................................................................................... 4
  1.2 Possible Mission Scenarios .......................................................................................... 4
2.0 Scope ............................................................................................................................. 4
3.0 Design ............................................................................................................................ 4
  3.1 Imposed Design Requirements .................................................................................... 5
  3.2 Speed ........................................................................................................................... 5
  3.3 Streamlining ................................................................................................................ 6
  3.4 Main Pressure Hull ...................................................................................................... 6
  3.5 Propulsion .................................................................................................................. 6
    Figure 3.5.2 Kort Nozzle Propeller .............................................................................. 7
3.6 Power Supply ............................................................................................................... 7
3.7 Control System .............................................................................................................. 8
    Figure 3.7.1 Control System Gearing ........................................................................... 8
    3.7.1 Rotation Speed ....................................................................................................... 9
    3.7.2 Torque Reduction .................................................................................................. 9
    3.7.3 Ballast Weight ....................................................................................................... 9
    3.7.4 Future Control System Considerations .................................................................. 10
    3.7.5 Control System Mounting .................................................................................... 10
3.8 Microprocessor ............................................................................................................ 10
4.0 Calculations .................................................................................................................. 10
  4.1 Calculation Assumptions ............................................................................................ 11
  4.2 Determination of Required Weight .......................................................................... 11
    Figure 4.2.1 Weight Analysis ....................................................................................... 12
  4.3 Determination of Required Thrust ............................................................................. 12
    Figure 4.3.3 Drag Verses Reynolds number for 3D bodies. .......................................... 13
    Table 4.3.1 Drag-Velocity Analysis .............................................................................. 14
  4.4 Calculation of Required Propulsion Power and Torque ............................................ 14
  4.5 Battery Housing Buoyancy Analysis .......................................................................... 15
    Table 4.5.1 Weight-Buoyancy Analysis ....................................................................... 15
5.0 Failure Redundancy ..................................................................................................... 15
6.0 Parts Identification and Budget .................................................................................. 16
7.0 Further Design ............................................................................................................. 17
  7.1 Design Decisions ........................................................................................................ 17
8.0 Timeline ....................................................................................................................... 17
  8.1 Appended Timeline .................................................................................................... 17
  8.2 Further Processes ....................................................................................................... 18
Works Cited ...................................................................................................................... 19
List of Used Formulas ....................................................................................................... 20
Appendix ............................................................................................................................ 21
Executive Summary

This progress report includes a condensed summary of the design process completed to date. The process has been designed to achieve a final goal of an untethered, free-swimming underwater system. This system has been designed to operate in any underwater environment with emphasis on small over-head environments. Due to time and budget constraints, we limited our design to the Autonomous Underwater Vehicle platform and place control electronics programming as an optional endeavour.
Design of an AUV Platform

1.0 Objective

1.1 Statement

The objective of this project is to design Autonomous Underwater Vehicle platform in which to house control electronics and instrumentation. This vehicle will be an untethered, free-swimming underwater system capable of operation in small enclosed environments, i.e. caves and wreck interiors.

1.2 Possible Mission Scenarios

This AUV platform could take part in three basic tasks: Oceanographic sampling, exploration, and observation. Oceanographic instrumentation can be added to assist in sampling and data collection in precise locations. Through exploration, remote bathymetry data can be collected without tedious measurements and/or personal risk especially in overhead environments. Finally, as an observation platform, the AUV would give cost effective access to deep regions without personal risk due to small operating costs and unmanned operation.

2.0 Scope

We will limit our design to the design of a main pressure hull, propulsion, streamlining appendages, power supply, and basic control systems. We will also include the necessary electronics needed to control the AUV. Programming of the vehicle is beyond the scope of this project due to the complexity and infinite variety of program types.

3.0 Design

The primary goal in this design is to insure the capability of operating in small overhead environments. These environments include, but are not limited to, submerged cave systems, shipwrecks and pipe inspection. Designing for overhead environments can be easily justified. First, any AUV capable of manoeuvring in overhead environments will be equally or better suited to open water environments. Most overhead environments offer the same environmental hazards as open water, but have additional hazards. These additional hazards may include small operation areas, dangling wires, sharp objects, and/or dense floating debris. This adds a margin of safety to normal open-water operation. Next, due to limited accessibility to overhead environments, very little
is known. This is due to the hazardous nature of most overhead environments. Of the various methods of penetrating such environments, each contains dilemmas: a diver is limited by his/her gear, depth, and time; a manned submersible is too large and expensive; and a remotely operated vehicle is limited by its tether. A small AUV system would be free of a tether and at the same time would be cheap and expendable.

Exploration of overhead environments can be very beneficial. Using an AUV in 3D mapping of submerged cave systems could: aid geologist in their pursuits; give rare insight into the biology of such systems; and eliminate the dangerous manned cave mapping, possibly saving lives. Interior wreck exploration using AUV systems could eliminate the normal expense of manned submersibles or salvaging costs and with little disturbance to the resting place.

3.1 Imposed Design Requirements

Numerous design requirements were imposed to insure the success of this design in its operating environment. The ability to enter small overhead environments requires a new and highly mobile design, featuring: The ability to spin about an axis within its own body; the ability to move/spin in any direction; precise control; streamlining to help prevent entanglement; and small, compact size. In addition to the design requirements imposed by overhead environments, normal operation and environmental hazards imposed certain needs. These needs include: Streamlining; low power consumption; neutral buoyancy; pressure resistance; and adequate speed to counter any currents.

In this design, it is desired to have as many off-the-shelf components as possible, speeding the design process; making the design very reliable; and simplifies the replacement of parts. Using off-the-shelf components not only require knowledge of their intended use, but also requires locating suppliers that will provide these components at a reasonable price. The Internet was used extensively in locating suppliers of required design components.

3.2 Speed

The design cruise speed of a 20” sphere has been determined by finding a minimum drag coefficient and thus the minimum thrust needed to maintain a reasonable speed. The maximum speed will be determined by the remaining power available. See section 4.3 for further details. The true cruise speed will be determined by in-water testing.
Streamlined appendages will be added to the exterior of the vehicle to cover system housings and assist in streamlining the system as a whole. Streamlining will be attained by adding a cone type shape to the rear of the sphere, producing a quasi-streamlined body.

In addition to a streamlining cone, a cover will help protect and streamline the thruster and battery housings. This will help to increase efficiency and prevent entanglement.

Figure 3.3.1 will give a general basis of the reduction in drag due to a streamlining cone based on its determined size.

3.4 Main Pressure Hull

The main pressure hull will be a hollow acrylic sphere donated by Advanced Game Concepts. A sphere is excellent for this design due to: fair to good hydrodynamic qualities; excellent pressure resistance; high manoeuvrability due to the ease of rotation; and finally, the fact that it is a very simple and studied shape. Spheres do not contain a uniform cross-sectional area over any length, which produces difficulty in adding segments without extremely altering its shape.

3.5 Propulsion

The main pressure hull will be propelled through the water by two stepper motors mounted in a cylindrical pressure housing on the rear of the sphere. These motors will drive propellers via a flexible shaft which will give the unit forward, reverse and yaw movement. Yaw movements will act around the centre of the pressure hull, creating a...
zero turning radius. The propellers will meet or exceed required design thrust. In this
design, two motors help aid in emergency event procedures as discussed in Section 5 of
this report.

Model boat propellers will be used due to our size requirements. Unfortunately,
model boat propellers have no design information aside from their diameter and pitch.
Counter-rotating Kort Nozzle propellers have been located and will be used in this
design. A sales representative was stated that a 3” diameter version of this propeller was
capable of producing approximately 5 pounds of thrust. This meets and exceeds
requirements.

![Figure 3.5.2 Kort Nozzle Propeller](image)

Stepper motors are being utilized for several reasons. First, a model boat motor
may suit this purpose, but no design information can be found for such motors. Second,
motors which meet size and torque requirements are very expensive. Finally, the control
of a normal DC motor is limited. A stepper motor is small; has the required torque; is
inexpensive; and can be controlled very effectively.

3.6 Power Supply

The transport batteries in a safe and efficient manner is very necessary in this
design. Safety is a concern due to the possibility of battery leakage and/or off-gasing,
seepage of hydrogen due to chemical processes in the battery. Any leakage could cause
shorts in electronic components and the escape of hydrogen can cause an explosive
situation that needs to be avoided at all costs. Due to these concerns, the batteries will be
placed on the exterior of the pressure hull in cylindrical pressure housings.

Cylindrical pressure housings will be mounted to either side of the sphere, while
insuring ease of removal and replacement. These cylinders have been designed to
accommodate off-the-shelf size C and D batteries. Each housing is designed to carry six
batteries; a pyramid shape of three, stacked. This battery layout takes advantage of the
available space. There will be eight C cell size and two D cell size housings. In place of
battery housings, instrumentation housings of the same dimensions can be used. In this
manner, limited modularity is achieved. Waterproof electronic connections are needed
to maintain the fast exchange of battery/instrumentation housings. It is desired to have
each individual battery housing neutrally buoyant, reducing required trim calculations
before each dive. See the Appendix for sketches of housing placement and size.

The maximum mission duration will be determined by the onboard power
available. If long mission duration is a goal, minimal instrumentation housings will be
used. The maximum voltage and current will be determined by the individual electronic components involved. Regardless, electronic voltage regulation will be used to ensure correct voltage is supplied to different electronic components.

3.7 Control System

The control system has proven thus far to be the most complex aspect of this design. Two designs have been proposed, one of which is considered a base design and the second is considered a “backup” design. The backup design differs from the base design in that two additional thrusters are added to give roll and lateral movement. Due to similarities, the base design can be quickly and easily converted into the backup design.

![Control System Gearing](image)

Figure 3.7.1 Control System Gearing

The control system shown in Figure 3.7.1 is considered the base design and was chosen due to: its precise control; innovation; and minimised moving components external to the sphere. The problems inherent in the base design include: the fact that it will occupy internal space; possible oscillation; and possible slow rotation speed. The base design control system uses a controllable stability system. Simply, a dead weight is moved inside the sphere to produce a righting moment on the entire system, causing a rotation. This weight will have access to the entire inner surface of the sphere creating the ability to pitch and roll in any direction. Yaw in the system will be generated by the propulsion system.

This system give precise and predictable control of the orientation of the AUV in pitch and roll, whereas the backup system requires calculating the final orientation. These calculations contain many unpredictable errors. These errors include propeller
slippage and non-uniform drag. The base design is similar to the backup design in yaw, i.e. calculation of the final orientation will be required.

A controllable stability system of this type has particular considerations. First, internal electronics must remain stationary while allowing the weight to move freely. Secondly, electronic connections must be allowed to run from the internal electronics to the exterior of the pressure hull without interfering with the weight mechanism. Thirdly, emergency event procedures must be taken into account. Next, the internal space occupied must be minimised. Finally, the desired speed of pitch and roll must be defined.

3.7.1 Rotation Speed

The most important factor in the control scheme depicted in Figure 3.7.1 is the pitch speed. This unit must pitch from a horizontal position to change its depth, and pitch back to a horizontal position to resume lateral motion. During the time that is required to perform such a manoeuvre, environmental conditions such as currents could drastically compromise its position. Therefore, it is desired to have the pitching rotation speed as fast as possible while avoiding oscillation. The design pitch speed is based on extreme hypothetical current speeds. The distance the AUV would be pushed by currents was predicted based on the predicted drag and proposed rotation speed. It was decided that the AUV should be able to perform one full revolution in six seconds or less. If this becomes unattainable due to other requirements, the backup design will be evoked for the sake of the safety of the AUV.

Roll speed is much less important and will be reserved for data collection manoeuvres and emergency event procedures. While collecting data, roll may be required to insure complete and thorough data sets.

3.7.2 Torque Reduction

Stepper motors will be used to drive the pitch and roll mechanism. These motors have the ability to rotate to a specified angle, allowing precise control of the pitch and roll mechanisms. A stepper motor’s torque is a function of its size and the desired speed. Reducing the required torque would increase the stepper motor’s available speed, reduce its size and minimise its power requirements. Torque reduction will be accomplished using a 6:1 ratio for pitch and an undetermined, approximately 180:1, roll ratio.

3.7.3 Ballast Weight

The weight used to offset the centre of gravity will simply be a formed chunk of lead. It is preferred that this weight be useful to the AUV mission, but the complexity of this task creates too many risks. It is also preferred that the weight be mounted to the internal gear in a manner facilitating ease of replacement. This will allow optimisation of the total weight verses required rotation speed for each mission.
3.7.4 Future Control System Considerations

Considerations to the future of this AUV platform have been made to insure the appropriate operation in other mission scenarios. These scenarios include sampling and manipulation. Each of these missions would alter the stability characteristics of the system, possibly in a negative way. This control system considers such effects and in most instances, can counteract them. The changing weight characteristics of the system is beyond the scope of this control system due to the fact that no dynamic buoyancy features have been added to this design.

3.7.5 Control System Mounting

The entire control system must be rigidly mounted to the sphere in a non-destructive manner. Two "sockets" mounted on either side of each hemisphere. The sockets will be permanently mounted to the sphere using a bonding agent. Upon coming together to form the sphere, these sockets will lock the internal mechanism in place. This method has both non-destructive qualities and a flat profile which will not interfere with the control system itself. This mounting method allows easy removal of all the internal components for serviceability and maintenance. This ease of accessibility will aid in the system's function as an academic test-bed for electronic systems.

3.8 Microprocessor

The microprocessor that will be used in the AUV is a Trenton Technologies 386 processor. It has one megabyte of RAM and its dimensions are 7" x 4" so it will easily fit within the vehicle. To program the microprocessor a C language will be used, although Assembly can be used as well in future projects. The microprocessor will be the main "brain" of the submersible; it will control the propulsion system, the weight-rotation system, and all of the motors. In the future when the AUV is upgraded and used for specific assignments, additional equipment such as a compass, a camera, and a navigation system may be added within the AUV and connected to the microprocessor. On the outside, SONAR sensors can be added and controlled by the microprocessor. All of this equipment will be crucial in any future projects that call for navigation within a small overhead environment such as a sunken ship or underwater cave.
4.0 Calculations

4.1 Calculation Assumptions

Certain assumptions were made to simplify calculations involved with this design. Any assumption made in the design process has been conservative in nature, i.e. adding a margin of safety to the design.

It has been assumed that the main pressure sphere in this design is solid. This holds true due to the fact that the sphere will be filled with electronic and control system components. This simplifies the calculation of the mass moment of inertia which is required in determining required torque.

It has been assumed that the diameter of the main pressure sphere is of a length equal to the actual diameter of the sphere plus the largest exterior appendages. This adds a factor of safety to the required thrust calculations.

4.2 Determination of Required Weight

The dead weight in the system will alter the centre of gravity of the entire system. It is assumed that the centre of buoyancy acts in the centre of the sphere. The distance between the centre of gravity and the centre of buoyancy is found using the equation below.

\[ GB = R - \frac{m_w K G_i - R(m_l - m_w)}{m_t} \]  \hspace{1cm} 4.2.1

Where: \( m_w \) = mass of weight  
    \( m_t \) = total mass of the system  
    \( K G_i \) = distance from keel to centre of gravity of the weight  
    \( R \) = radius of the sphere

Next, the righting moment at any angle of inclination can be found by:

\[ M_r = \Delta GB \sin \phi \]  \hspace{1cm} 4.2.2

Where: \( \Delta \) = displacement of the system  
    \( \phi \) = angle of heel

From basic Physics, we know that torque and moment are the same. This yields the following expression.

\[ I \alpha = \Delta GB \sin \phi \]  \hspace{1cm} 4.2.3

Where: \( \alpha \) = angular acceleration  
    \( I \) = mass moment of inertia
From Equation 0.2, it can be seen that the maximum righting moment will occur at an angle of heel equal to 90°. Therefore, to assure rotation of the entire AUV system, the following must be true:

$$\Delta GB > 1\alpha$$  \hspace{1cm} 4.2.4

This avoids a situation in which the weight travels freely without producing a desired rotation on the AUV.

![Graph showing Required Angle of Heel versus Weight for a 20" Sphere](image)

**Figure 4.2.1 Weight Analysis**

Figure 4.2.1 shows the required angle to produce the design angular acceleration. Four pounds has been chosen to give required design rotation speed and an extra factor of safety and flexibility in the design.

### 4.3 Determination of Required Thrust

The thrust required to maintain cruise velocity is less than the thrust required to achieve cruise velocity. This is due to a changing drag coefficient with a changing velocity. With this considered, the minimum thrust requirements will meet the maximum drag experienced while accelerating to cruise velocity.

Upon finding the Reynolds number at increasing velocity intervals using the equation below:

$$R_e = \frac{V_oD\rho}{\mu}$$  \hspace{1cm} 4.3.1
Figure 4.3.3 Drag Verses Reynolds number for 3D bodies.

the drag coefficient for each value was obtained using Figure 4.3.1 found in Engineering Fluid Mechanics (Figure 11.11, p. 438). Next, each drag coefficient was used in the equation below:

\[ F_d = \frac{C_d \rho A_p V_o^2}{2} \]  

4.3.2

yielding the drag force acting on a sphere varying velocities. Results of this are shown below:
Table 4.3.1 Drag-Velocity Analysis

From Table 4.3.1, it can be seen that between a compromise in speed versus efficiency, that a design speed of 4 knots would fit the propeller thrust and be an adequate speed.

4.4 Calculation of Required Propulsion Power and Torque

Due to the fact that no formal design specifications were given with respect to the propellers, an alternative method to find power and torque was used. This method involved first finding the power required to propel the sphere through the water using the equation:

\[ P = F_d V \]  

4.4.1

Next, this power was related to torque by:

\[ P = 2\pi Qn \]  

4.4.2

Where \( Q \) = Torque
\( n \) = revolutions per second

The required torque to produce the calculated effective power was found.

Table 4.4.1 Torque Requirements

Due to the fact that two motors will be used, the torque required for each motor will be reduced by a factor of two. It is desired, for emergency procedure, to insure that each
motor will theoretically be capable of achieving the design speed. Thus, as a factor of safety, each motor will be able to produce the total required torque at the required speed.

It can be seen that either stepper motor shown above has the design characteristics to handle 12 oz-in at 16600 steps/sec.

4.5 Battery Housing Buoyancy Analysis

A weight verses displacement analysis is required to determine the buoyancy characteristics of each battery housing. Due to the cylindrical shape of the housing, the total displaced weight can be described as:

\[
\Delta = \frac{\pi}{4} D^2 l \gamma
\]

where \( l = \text{housing length} \)

and the total weight of the housing is the housing weight plus the weight of the batteries:

\[
W_{\text{hou sin g}} = \frac{\pi}{4} \rho_{\text{hou sin g}} \left[ D^2 - (D - 2t)^2 \right] (l - 2t) + \left( 2\pi D^3 \right) + W_{\text{batteries}}
\]

Where: \( t = \text{wall thickness} \)
\( l = \text{housing length} \)
\( \gamma = \text{housing material specific weight} \)

Finally, the net buoyancy is:

\[
W_{\text{net}} = \Delta - W_{\text{hou sin g}}
\]

<table>
<thead>
<tr>
<th>Type</th>
<th>SG Housing</th>
<th>SG water</th>
<th>Diameter</th>
<th>Length</th>
<th>Thickness</th>
<th>W (battery)</th>
<th>W (housing)</th>
<th>Displacement</th>
<th>W (net)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n/a</td>
<td>lb/in^3</td>
<td>lb/in^3</td>
<td>in</td>
<td>in</td>
<td>in</td>
<td>lb</td>
<td>lb</td>
<td>lb</td>
<td>lb</td>
</tr>
<tr>
<td>C</td>
<td>0.052</td>
<td>0.0370949</td>
<td>2.5</td>
<td>4</td>
<td>0.125</td>
<td>1.04625</td>
<td>1.291932363</td>
<td>0.7283568044</td>
<td>-0.563576</td>
</tr>
<tr>
<td>D</td>
<td>0.052</td>
<td>0.0370949</td>
<td>3.25</td>
<td>5</td>
<td>0.125</td>
<td>1.9125</td>
<td>2.323459589</td>
<td>1.538653748</td>
<td>-0.784806</td>
</tr>
</tbody>
</table>

Table 4.5.1 Weight-Buoyancy Analysis

Table 4.5.1 shows that each battery housing will be have negative buoyancy when submerged. To achieve neutral buoyancy, foam may be attached.

5.0 Failure Redundancy

This AUV, as stated before, has been designed to negotiate over-head environments. These environments require very good failure procedures due to the fact that surfacing may not be directly accomplished. Therefore, this design must be able to manoeuvre with only partial operation of the control system. Each element of the control
system of this design was analysed to determine the redundancy of this AUV system. Some known failure modes are listed below:

1. Failure of both propulsion motors would lead to the inability to manoeuvre.
2. Failure of the roll mechanism while in a 90° roll orientation would lead to the inability to turn left or right.
3. Failure of the roll and pitch mechanism would leave the AUV without the ability to leave the imaginary plane created by the thrusters.

Note that these failure modes are only with regards to the control system of the AUV and do not take into account any other circumstance, i.e. power failure, etc. Due to these failure modes, several design modifications have been made to both the physical mechanics and operation procedures. First, the roll mechanism will be reserved for data collection and will be designed to fail in a fixed position. Failure in a fixed position will be accomplished using a worm-gear attached to the stepper motor. This assures that upon failure of the motor, no roll can be induced by environmental conditions. It is hoped that through these changes, any failure of the roll device will be in a near horizontal orientation. Second, the pitch mechanism will be altered to carry two stepper motors and will be designed to fail in a free moving manner. Two stepper motors, each capable of pitching the AUV, will insure redundancy. Free moving failure mode of the pitch mechanism will allow the main propulsion system to achieve pitch motions by using a rolling motion first. I.e. roll to a 90° orientation; induce torque with the propulsion system until the pitch mechanism returns to 0° and roll back to 0°. This type of operation, although convoluted, hopefully allows the AUV to return to a safe location to abort the mission.

Even upon the failure of one main propulsion motor, the AUV will retain its ability to manoeuvre. This will be accomplished by rolling the AUV to 90°, and using the thrust-weight vector combination to produce forward motion. Any turning will be achieved through roll followed by thrust.

Please note that these emergency procedures ignore environmental hazards such as currents. These procedures can be performed, but their effectiveness will be determined by the environmental conditions present upon failure. The main problem inherent with these failure procedures is the increased time required to perform them, leaving the AUV vulnerable.

6.0 Parts Identification and Budget

Many parts have been determined over the course of this design process. Currently, many parts have been generously donated by several different companies: Advanced Game Concepts, Dumas Products, and American Scientific and Instrumentation. The donated parts have a total estimated cost in excess of 500 dollars. Of course, parts will still need to be acquired:

1. Propellers ≈$50 each x2 $100
2. Propulsion Motors ≈$30 each x2 $60
3. Raw Materials Estimated $300 n/a $300
For 8 C-cell housings, 4 D-cell housings; propulsion housing; propulsion tubes, miscellaneous control system and mounting apparatus.

4. Miscellaneous  
5. Batteries*  
   30 Rechargeable C-cells  
   20 Rechargeable D-cells  
*To be decided later.

$150

≈$220  
≈$220  

7.0 Further Design

The next process in this design will be to determine the size, type, and placement of the main propulsion motors. The main propulsion will be placed in a tunnel, and this tunnel, intakes and out-takes, must be designed to achieve efficiency.

Then, the battery tubes will be designed and placed on the AUV. The weight characteristics of these tubes must be taken into account. If it is found that they are too heavy, foam will be used to bring them to neutral buoyancy.

Finally, the streamlining process will begin. The streamlining cone will be left for last in this process due to the fact that its pure function is hydrodynamic streamlining and has no impact on preventing entanglement.

7.1 Design Decisions

It may be decided to eliminate any streamlining attempts. This will be based on the fact that this design will be a test platform. The tested properties of this design will not be affected by eliminating streamlining, though the lack of streamlining will yield less data that can be used in further designs of this type.

8.0 Timeline

8.1 Appended Timeline

The appended timeline is as follows:

Week Ending:  
May 21-  
1. Design of the internal gear using AutoCad.  
2. Identify local supplier of pressure housing parts.  
3. Acquire known parts.  
May 28-  
1. Export internal gear design to MasterCam and mill out the internal gear.  
2. Construct the control system.
3. Start coding and programming the microprocessor to control the various systems of the AUV.

June 4-
Cruise Week
-Sit and brainstorm?

June 11-
1. Construct pressure housings for propulsion and batteries.
2. Connect various electrical components to the microprocessor and test to see how well the processor controls each component.

June 18-
1. Build the propulsion tube.

June 25-
1. Construct mounting brackets and begin final assembly.
2. Finalise testing of completed AUV and test in pool.

8.2 Further Processes

The following processes may be performed at a yet undetermined period of time.
1. Testing of the control system to determine its effectiveness. If it is ineffective, the “backup” design will be initiated.
2. If streamlining appendages are used, wind-tunnel testing will take place to determine the drag and ultimately, the cruise speed for the design.
3. Add a sensor package which will easily interface with control electronics in the future.
Works Cited


List of Used Formulas

\[ GB = R - \frac{m_w K G_i - R (m_i - m_w)}{m_i} \]

\[ M_r = \Delta GB \sin \phi \]

\[ \tau = a l \]

\[ \Delta_{sphere} = \frac{\mu \pi}{6} D^3 \]

\[ I_{sphere} = \frac{2}{5} m R^2 \]

\[ S_{sphere} = \pi D^2 \]

\[ F_d = \frac{C_d \rho A_p V_o^2}{2} \]

\[ R_s = \frac{V_o D \rho}{\mu} \]

\[ \alpha = \frac{2 \theta}{l^2} \]

\[ A_{sphere} = \frac{\pi}{4} D^2 \]
## Appendix

<table>
<thead>
<tr>
<th>Actual Diameter (m)</th>
<th>0.33</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>20° Sphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assumed Diameter (m)</td>
<td>0.51</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume (m³)</td>
<td>0.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>19.34</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Displacement (N)</td>
<td>197.93</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moment of Inertia (kgm²)</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum Weight</td>
<td>0.99</td>
<td>2.18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>lb</th>
<th>kg</th>
<th>GB (m)</th>
<th>Righting Moment (N-m)</th>
<th>Final Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1.36</td>
<td>0.01</td>
<td>1.57</td>
<td>46.55</td>
</tr>
<tr>
<td>4</td>
<td>1.81</td>
<td>0.01</td>
<td>1.57</td>
<td>32.99</td>
</tr>
<tr>
<td>5</td>
<td>2.27</td>
<td>0.02</td>
<td>1.57</td>
<td>25.82</td>
</tr>
<tr>
<td>6</td>
<td>2.72</td>
<td>0.02</td>
<td>1.57</td>
<td>21.28</td>
</tr>
<tr>
<td>7</td>
<td>3.18</td>
<td>0.03</td>
<td>1.57</td>
<td>18.13</td>
</tr>
<tr>
<td>8</td>
<td>3.63</td>
<td>0.03</td>
<td>1.57</td>
<td>15.8</td>
</tr>
<tr>
<td>9</td>
<td>4.08</td>
<td>0.03</td>
<td>1.57</td>
<td>14</td>
</tr>
<tr>
<td>10</td>
<td>4.54</td>
<td>0.04</td>
<td>1.57</td>
<td>12.58</td>
</tr>
<tr>
<td>11</td>
<td>4.99</td>
<td>0.04</td>
<td>1.57</td>
<td>11.42</td>
</tr>
<tr>
<td>12</td>
<td>5.44</td>
<td>0.04</td>
<td>1.57</td>
<td>10.46</td>
</tr>
<tr>
<td>13</td>
<td>5.9</td>
<td>0.05</td>
<td>1.57</td>
<td>9.64</td>
</tr>
<tr>
<td>14</td>
<td>6.35</td>
<td>0.05</td>
<td>1.57</td>
<td>8.95</td>
</tr>
</tbody>
</table>

Table A.1 Data used to create Figure 4.2.1
Front View

Top/Side View

3.5'

L