Sublime

Springstead High School/Central High School
Hernando County Schools

13th International Human Powered Submarine Race – June, 2015

TECHNICAL REPORT

SUBLIME EXECUTIVE SUMMARY

The original Sublime (2-man version) raced for the first time in the 2nd International Human Powered Submarine Race in 1991 and again in 1993 as an independent entry. It raced for the third time in 1997 in conjunction with South Broward High School.

In 2002, Steve Barton, while teaching in the Construction Technology class at F. W. Springstead High School in Hernando County, Florida, decided to continue the tradition of exposing high school students to the engineering challenges of submarine design, construction, and racing by building a new 1-man submarine, using composite technology, for the 2003 7th ISR.

Between 2003 and 2009, the Hernando County Schools' students made modifications to the one-man submarine and in 2009 took first place in overall performance. 2011 and 2013 brought more changes. For the 2015 race it was determined that the entire submarine, except the actual hull, would be totally reworked, with the goal of finally achieving speeds in excess of 6 knots.

INTRODUCTION

The Sublime Race Team is comprised of 15 students, from Springstead and Central High Schools in Hernando County. We are fielding a team with only 2 of the 15 students having had experience in previous races. Four former team members, who are currently in university undergraduate and graduate programs, the military and careers will be overseeing the operations. Numerous other students were involved through the Springstead High School after-school Submarine Club but were unable to participate in the race for various reasons. In the design phase students from core classes in math and science were involved.

DESIGN PHILOSOPHY

Sublime's design is a single pilot wet sub. Fiberglass and epoxy were the primary construction materials, although steel and plastics were also used. Hull dimensions are 22 inches in height, 20 inches in width, and just over 11ft, 6 in. in length. The original hull was modified in 2007 by the addition of two pods to increase knee clearance. It was anticipated that the addition of these pods, asymmetrically, would cause additional drag and upset the steering balance. Therefore, the pods were lengthened and streamlined to minimize drag.

NACA 66-0015 was chosen as the master profile because it had a low coefficient of drag and a relatively thick foil. The pervasive theme was to minimize internal volume to the level just adequate to do the job. This theme required careful placement of the required components with no compromise to safety. Our goal was to maximize laminar flow, and therefore minimize boundary layer turbulence. All controls and the propeller were placed aft of the potential laminar flow region.

The philosophy behind the design modification for the 2009 race was to transition from a highly maneuverable design that in the past had not been competitive against submarines designed for a straight (drag race) venue.

Our focus for the 2011 race was to continue to minimize the effects of over-steering by improving the cable system and reducing the amount of travel as well as two new, hand-made propellers based on different propeller theories. For 2013, the team built Sublime's 4th totally different drive train to achieve better reliability and efficiency.

For 2015, the only constants were the basic hull shape and the new 2013 drive train. An analysis of our 2013 performance showed that our steering system could be improved by reducing the fin thickness as well as the overall size of the fins. The pedal mechanisms were redesigned to make loading the submarine more efficient with locking stops. The windows were enlarged and an additional window was added to the bow of the submarine so the pilot could see further down the course. It was noted by the Navy divers that our sub seemed to reach its maximum speed at the end of the course. As the official time trap is much earlier in the course, the students concluded that we had to have a faster takeoff. Several different multi-blade props have been designed and constructed.

As usual, monetary constraints have necessitated the use of off-the-shelf technology and home made parts. However, the driving force behind why we build it all ourselves is the desire to make this a real learning experience for our students.

DESIGN AND FABRICATION

Hull Construction

What follows is an historical narrative of the fabrication and subsequent modifications made to the hull prior to 2015. We did not see any reason to make any major changes to the basic hull shape.

The current hull was built for the 2003 race. The sub began as a male plug constructed from plywood. Each station was drawn from a table of NACA 66-0015 coordinates. An elliptical shape was created by utilizing a fixed ratio ellipse generator (string system with two nails). After all the station bucks were carefully placed on a central beam, foam was added between each station to give a rough form to the male plug. Plaster was added over the foam and carefully crafted into a true shape.

The male plug was coated with three layers of varnish. It was sanded a final time and given multiple coats of form release agent. One layer of 8 oz. bi-directional e-glass was placed over the plug, followed by three layers of 1.5 oz. unidirectional. Epoxy was liberally added. The result was a female mold of ½ of the sub. Since the sub was originally symmetrical, only one female mold was necessary. The female mold was given finish work and placed into action.

The female mold was treated with mold release agent and two layers of 8oz. bi-directional e-glass were placed at 45 degrees to the chord axis. The bow was built up with 10 layers of cloth. Two layers of 1.5 oz. unidirectional mat were placed at a 30 degree bias and additional layers of mat were placed at critical areas. Marine epoxy was liberally applied to the e-glass. The whole mold was then covered with plastic, sealed, and a 13 in. vacuum was applied to ensure conformity to the mold and enhance strength characteristics. A second shell was made in a similar manner, except a joggle was molded in to aid in joining the two halves.

The halves were mated. Openings for a window and a hatch for entrance and egress were cut. The areas around the openings were strengthened with additional layers of mat. Much time and effort was put into making the sub smooth.

A male plug was made off the female mold for the window. A piece of ¼ in. plexiglass was heated and drawn over the mold.

It was trimmed and installed on the sub body. The installation made the plexiglass a load-bearing member of the sub.

One of Team Sublime's educational goals is for all of the students to participate in as many of the aspects of submarine construction and operation as possible. This necessitates that the submarine design be adaptable from 5 ft, 90 lb girls to 6ft 5in., 250 lb boys. The 2005 race showed us that the larger boys were clipping their knees on each revolution, making for erratic propeller movement. To solve this problem, knee pods were added for the 2007 race.

The pods were constructed by slabbing on high density foam, faring it to the most optimal shape, covering it with epoxy glass, and finishing it. Then the internal hull was removed in the pod areas.

The basic hull is the same as it has been since 2007.

Control Surfaces

In 2003, the rudders and dive planes were inadequate to control the submarine. It was side slipping and not tracking. For the 2007 race, mid-hull pivot fins were added horizontally and vertically to minimize the side slip and provide a pivot point. Additionally, a new control mechanism was constructed utilizing caged cables.

In 2009, in order to overcome over-steering, we added stationary horizontal control surfaces. The purpose of this modification was to limit over-steering and place the control system into stable equilibrium when tracking down the course.

Because salt water practices had taken their toll on the steering system over the past 12 years, the team decided to build a totally new system incorporating design changes and more corrosive resistant materials. The physical thickness of the elevators and rudders were causing drag. To correct that, the wing profile was changed to a thinner, high speed, reduced wetted surface area profile.

Hatch and Safety

The hatch lock is crafted with a spring to remain closed. A cable is attached and routed to the front of the sub next to the pilot's face so he/she could easily release the hatch. In addition, there is a large pin where the diver can take his/her left foot, press, and open the hatch. An outside lever incorporated into the mechanism assures that outside help has immediate access to the pilot of the sub. An emergency float system with, as of 2013, an improved, positive locking latch is spring loaded and must be held at all times on the control lever.

A strobe light is incorporated in the top of the submarine for easy location by Navy divers.

Propulsion

The paragraphs later in this section are an historical summary of the evolution of Sublime's propulsion systems. The modifications made in 2013, as explained later, produced a reliable and efficient drive train. For 2015, Sublime's propulsion system change will focus on new propellers.

For 2013, the students fabricated, again by hand, a new stainless steel propeller that will be able to absorb the additional energy that will be generated by the new drive train.

In 2003 SubLime's drive train was the rear axle from a Mustang. Based on 2003 race results, we determined that low shaft rpm was limiting our speed. We retained that concept through 2005, and in 2007 we decided to go with a combination of chain/sprocket to spiral/bevel gear (1 to 2) ratio to obtain a 6 to 1 or greater pedal to shaft ratio. We ran this drive train through 2011.

Our research supports the fact that, under human power, between 50 and 80 revolutions of the bicycle crank are possible under water, thus yielding 200 to 400 shaft rpms. Computations helped determine the optimum pitch at the anticipated revolutions.

The 2009 generation of propeller design was assisted by the use of Java Prop programming. We designed and fabricated our own propellers to Java Prop specification and compared them to our previous propeller calculations. We experimented with different surface areas and diameters which lead us to the conclusion that the diameter should not exceed 18 inches with a surface area of 30 sq. in. a blade +/- 5 sq in. We needed as high a ratio as possible and a smaller diameter propeller to keep the drag coefficient of the prop as low as possible.

The race results for 2009 seemed to give validity to our drive train system. However, we did not break the 6 knot barrier. For 2011 we designed two new propellers based on two different design theories. They're both thinner and more polished than the 2009 prop. For that race, we again used the Java Prop program and used an MA409 wing shape to hopefully improve our performance another 10%. The bottom cord of the wing is concaved to improve the flow off the back of the prop. The primary difference between the two props is diameter. We again fell just short of the 6 knot goal.

In 2013, the students fabricated, again by hand, a new stainless steel propeller that was able to absorb the additional energy that was generated by the new drive train. After input from the Navy divers at the end of the course, who stated that we were the fastest sub across the finish line, we realized that we weren't getting maximum thrust early enough in the course to do well in the speed trap.

A two bladed, lightly loaded prop, (circa 2013) although the most efficient overall, does not accelerate well enough to give us maximum speed at the speed trap. It doesn't have enough surface area to accelerate quickly. For 2015, the students have constructed two different multi-bladed propellers. The theory is that a full disc propeller will increase the surface area for a greater initial acceleration. They have shaped and welded these from stainless steel stock by hand.

<u>Life Support and Safety</u>

Life support is scuba. An air tank is strapped in the rear of the sub. A long hose carries air to the primary regulator. Air exhaust is vented through holes in the top of the sub. An emergency air system is placed on the diver for immediate access.

Safety has been a primary design concern. Collisions are possible, so the bow is heavily reinforced. Visibility through the window is excellent. The hatch is placed in the side and is larger than necessary to allow ease of entry and exit. The hatch floats free very easily. The propeller blades are painted red for visibility. The interior volume of the sub has enough room to perform, but is kept to an absolute minimum to reduce displacement. The larger boys have no issue with sliding forward while pedaling. However, the smaller girls do, and for them straps are attached to the hull, at the shoulder position, to stop the pilot from moving forward as a result of the inertia caused by the pedaling motion. However, these straps do not interfere with the pilot's ability to egress the sub quickly. High grade components are used at any critical point. The sub has a strobe light that provides a ready location. Perhaps the most important safety device is our assiduous attention to safety during design and practice.

TESTING

Sublime's primary testing locations is the Gulf of Mexico. From August, 2014 through the week before the 2015 race, students will have spent 4 hours every Saturday (weather permitting), in in-water testing. Team Sublime's challenge in testing is our commitment to allowing any student who wishes to be a pilot the opportunity to do so. Our current 15 member team consists of 13 new students, most of whom became scuba certified in the spring of 2014. Many hours have been spent getting the student acclimated to the conditions of submarine racing.

The practices operate in about 5 ft. of water and critique and refine the sub's performance. Testing so far has revealed numerous issues that have had to be resolved.

Measurements of air consumption under stress have been made. The air supply system has twenty to twenty-five minutes capacity depending on the pilot on board. Problems with Sublime so far have been minor in nature and are being resolved as weaknesses occur.

TRAINING

The Sublime team has certified 13 new divers. Scuba instruction was done in the spring of 2014 so as to give them time to become experienced.

Team members train using stationary bicycles, actual bicycling, and running. Several of our team members compete in high school athletics such as track and soccer. Although each team member trains according to his/her own, needs, they all are provided with plenty of swimming and diving experience during our in-water testing.

Our launch team will consist of four divers, each with a specific responsibility. All teams members will be trained in each support position and we must have total interchangeability, because who is piloting changes.

PROJECT SUMMARY

Our goal continues to be to inspire students to pursue careers in engineering. Sublime is a team effort in the best sense, and great satisfaction comes from watching a new group of high school students every two years discover the joys and frustrations of taking learning beyond the theoretical book knowledge of the classroom and into the realm of practical application.

Students with varying academic and career interests join forces to not only create a viable human powered submarine, but apply critical thinking and problem solving skills to the project – the same skills that will be required whether the student goes on to a university for engineering, a tech school, or the military.

This year's team consists of 13 new students, and 2 students who are from the 2013 race and are just graduating from high school. Four additional former team members are returning to help. One is in the Air Force, one is in Stanford studying for his PhD in physics, one if currently in the University of Florida, and one is an instructor/manager for sky diving training. Four members of our team are graduating high school this year and most have been part of the AP or IB programs.

Sublime is a model of how to do a lot with a little. The students have read extensively and have "picked the brains: of experts in many fields. When it comes down to the nuts and bolts of the submarine, these students have designed and fabricated everything themselves. They have constructed the plug to lay up the hull, built the drive train from scratch (excluding the actual gears), and hand forged the propeller.

When Springstead and Central High Schools/Hernando County Schools first became involved with the ISR in 2003, our budget consisted of small donations from friends and relatives. Ms. Susan Duval, who has recently retired as Principal of Springstead High School, and is now a member of the county's school board, was extremely supportive over the years. The current principal, Mr. Carmine Rufa, has continued that support.

We have grown in size and support with each race that passes. This year we are fortunate enough to receive grants from the Hernando County Education Foundation, and a Motorola STEM grant. If STEM is, as even President Obama has stated, pivotal to the future of America, projects such as Sublime build an interest, at the grass roots high school level, in the young students who will go on to be university engineering students, and ultimately a driving force in our nation.

In addition to the support we have received from our principal and the grants orchestrated through the Hernando County Education Foundation, we receive invaluable assistance from local sources. A local boat builder taught the students how to lay up a fiberglass hull. A local machinist instructed the students in the use of metal machining tools. A local bicycle shop and scuba instructor gave discounts on equipment. And the list goes on. All of these people see that an investment in high school students who are tackling a project such as this is a worthwhile endeavor, and we are eternally grateful.

The bottom line, as always, is for high school students to learn theoretical and practical engineering concepts and be exposed to networking with college engineering students and professors, as well as professional staff at Carderock. Additionally, some current, and many former team members are part of ROTC. Exposure and networking with MUDSUs and naval commanders could definitely influence their future.

Our philosophy continues to be to allow any student who is interested in piloting the submarine to be allowed to do so. Although we realize this may put us at a disadvantage in the race as compared to teams with one dedicated pilot, it’s a disadvantage we embrace and plan to run with, right over the finish line in first place.