S u b Zero

Springstead High School/Central High School

Hernando County Schools

13th International Human Powered Submarine Race – June, 2015

TECHNICAL REPORT

SUBZERO
EXECUTIVE SUMMARY

SubZero is the newest entry for Springstead and Central High Schools from Hernando County Schools. It was put into play in the 12th ISR. Like the submarines that the team has raced before, it is constructed totally by high school students, without using professionals. Most submarines in their debut year have problems. SubZero was no exception. In fact, it was awarded the first ever "Most Destructive Submarine" award for the fine job it did wrapping the underwater light system in its propeller. Despite the problems, SubZero finished first in the high school division for 2 person propeller driven and had the best time of any of the two man propeller driven submarines. Our all girl team holds the record in that category for female pilots.

INTRODUCTION

The SubZero race team consists of 15 high school students, 2 of whom participated in the 2013 race. Four former team members who are currently in college or the military are returning to supervise the current students.

DESIGN PHILOSOPHY

Construction of SubZero was begun in August, 2011, after the 11th ISR. The students chose to build a two-person, propeller driven submarine with both occupants pedaling. The basic idea was to get the maximum human power in the minimum amount of wetted surface area. The students hypothesized many different configurations. They settled on a design philosophy that maximizes efficiency in a minimal hull shape, by using only one drive mechanism. Most two person submarines use separate crank mechanisms, one for each pilot, which requires more space, and presents the problem of mechanically connecting them, thus causing more friction with more moving parts.

Previous entries by Hernando County Schools' teams were built around a bicycle chain mechanism. The SubZero team realized that the chain mechanism would not hold up to these forces.

DESIGN AND FABRICATION

Hull Construction

The students measured themselves and drew out full-scale drawings of how to manipulate positioning so that both pilots could

be in a natural pedaling position. They then designed a hull that would allow that positioning to be possible.

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. After all the station bucks were carefully placed on a central beam, students ripped thin cedar strips and fastened them on to the stations.

SubZero was designed to be 15 ft. 8 in. long and have a maximum diameter of 25 inches. The bow was rounded to facilitate turning maneuverability.

The half plug was sanded and covered with visquen and coated with mold release wax. The students manually laid up two half hulls using two layers of 12oz. bi-axial cloth with one layer of matt in between. The two halves were then joined together and the hull was fared out with polyester resin and microspheres.

The areas where windows were needed were cut out and the removed parts were used as molds for the lexan windows, which were manually formed.

One of Team SubZero'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 for pilots ranging from 5ft tall and 90 lbs. to 6ft. 3in tall and 225 lbs.

After the 2013 competition, the students evaluated the submarine's performance including input from the pilots on what worked and what didn't. The smaller pilots noted that when they pedaled hard at the start, they slid forward as there was no restraint to keep them in place. This resulted in them pushing the joy stick down and repeatedly nose diving into the bottom, from which position they couldn't recover. To correct this, the students designed a restraint system consisting of wedges for their shoulders to press against so they don't slide forward. These wedges must be removable to make room in the submarine for the larger students. Students originally considered straps, but switched to wedges because the straps could foul the regulator and mask.

Another design modification for the hull, toward the same purpose as the wedges, is a weight belt with Velcro sewn onto the outside of the belt. The hook portion of the Velcro is affixed to the roof of the submarine. This design not only stops forward motion, but also keeps the pilot's back close to the roof.

Because it is Velcro, and the belt is a quick release weight belt, it is easy for the pilot to extricate himself.

Control Surfaces

At the beginning of the initial construction of the submarine in the fall of 2013, the students unanimously voted to use a single joy stick steering configuration. Over 6 months they designed and built several different systems with input from aeronautical engineers and aircraft mechanics. Field tests in the Gulf of Mexico demonstrated that without a long enough lever arm, the wrist was not strong enough to actuate the rudders. Consequently, the students scrapped six months of work and redesigned the rudder mechanism to be a longer arm that would swing athwartship and give them the mechanical advantage necessary to operate the rudders.

This steering mechanism worked well in the 2013 race. We were able to stay on course as long as we could stay off the bottom of the basin.

SubZero has two vertical and two horizontal control surfaces that are actuated by Teleflex cables. On the forward third of the submarine three stabilizing fins are attached to help with tracking and provide a pivot point around which the force of the elevators and rudders can work.

Hatch and Safety

Two hatches sit on the port side of the submarine for most of the length of the pilots' bodies. Slide latches that are next to the pilot's face, and easily accessible, can be accessed from both the inside and the outside.

The emergency float/dead man system consists of two independent floats, one for each pilot, that are spring loaded so that upon release of the handle, they will rise to the surface.

SubZero's original rear window configuration was not adequate for the support or safety divers to keep visual contact with the rear pilot. Additionally, the rear pilots felt claustrophobic. The students cut out the hull so as to increase the window to one twice the size of the original.

Propulsion

The amount of human power generated in a two man submarine would be too great for a standard

bicycle frame. We determined that a new approach, without the bicycle chain and gearbox, was the only thing that would stand this much force. The team worked with a local machinist, learning how to use a metal lathe and a milling machine to create a straight 6 to 1 gear ratio.

The gears were off the self, but the remainder of the drive mechanism was home made. This entailed turning hubs for ball bearing races, machining pedal cranks, and welding supports for the gear train. This produced a robust mechanism that will stand up to our strongest pilots.

In researching two person submarines in the last several races, it appeared that they all used two separate crank mechanisms for the two pilots. This required a complex chain drive system to lock the two together. Our conclusion was that it would be simpler and much more efficient to use one bicycle crank with two pedal stations on it.

We realized that pedaling counter-clockwise, which is unnatural, did not produce nearly as much power. Therefore the only way to have two pilots connected to one crank system was to have one pilot on his/her stomach and the other pilot on his/her back so the two would both be pedaling in the normal clockwise direction.

Our first drive shaft was a stainless steel tube which, when torqued by two pedalers, began to “s” bend in the middle. We replaced it with a thick-walled stainless steel pipe that the students turned on the lathe. A plastic shield protects the rear pilot from the turning shaft.

Our 2013 propeller was hand made from flat stainless steel stock. It was heated red hot and forged into the shape dictated by the Java Prop program. Additional strengthening and filling was done with tig welding. Hand sanding and polishing completed the propeller. It worked efficiently, but was larger than the rear rudder, causing problems with it tangling with the light rope on the bottom of the basin. After this incursion, we shortened the propeller to eliminate the problem of it entangling the lights. We had a successful run with this, but our pilots stated that the change made pedaling too easy and we couldn’t maximize the benefit of having two people pedaling.

After the race, the students analyzed what had happened and researched alternative options. Amongst the options they studied was the use by large ships of full disc propellers. The students came up with the idea of a multi-bladed prop with a larger surface area in the actuating disc. We are currently testing a four and a six blade

propeller, both of which are smaller in diameter than the original prop. We believe they will keep our drag coefficient down. We anticipate a larger output due to the larger surface area on the multiple blades.

The speed trap is designed to record the highest speed. It seemed to us, as well as divers in the water in 2013, that we peaked at the end of the race, not in the speed trap. We theorize that the current propeller will allow us to accelerate sooner so we hit our maximum speed in the speed trap.

In the 12th ISR we had the foot portion of swim fins affixed to the pedal mechanism, and the pilots used these to keep their feet on the pedals. We had problems with the efficiency of our loading because of the fin straps, and it was even more of a problem for the pilots trying to get the strap off to get out of the submarine. For the 13th ISR we've gone to the same system we use in SubLime, which is bicycle shoes with slides that lock into plates on the pedals. Practice has shown that loading is more efficient, and they disconnect easily when getting out of the sub.

Life Support and Safety

Two 30 cu.ft. scuba tanks are mounted fore and aft. The front tank is located directly below the pilot's chest, and the rear tank is located on the ceiling above the pilot. The pressure gauges are easily visible to the pilots. The tanks are strapped into the submarine. Each pilot also wears an easily accessible spare air on his/her chest.

Safety has been a primary design concern. Collisions are possible, so the bow is heavily reinforced. There are two windows. The front window allows the front pilot to navigate the submarine and also allows the safety divers to view the pilot's face continually. For 2015 the rear window which was placed on the side directly in line with the face of the rear pilot was double in size so the safety divers could have a clear view, and the rear pilot wouldn't be as claustrophobic. Visibility through both windows is excellent.

The hatches float free easily when released. The pilots wear bicycle racing shoes, and these are affixed to the pedals using large plates attached to the shoes with a clip attached to the pedals. This allows the pilots to easily slide their feet out of the pedals sideways. The Velcro straps on top of the shoes are painted fluorescent orange for visibility by the support divers. The pilots' feet can be released by using these straps to free their feet from the shoes. The sub has a strobe light that provides a ready location.

Both hatches have clearly marked rescue squares. Both the propeller blades and the dive fins are painted fluorescent orange at the tip.

Perhaps the most important safety device is our attention to safety during design and practice.

TESTING

SubZero's primary testing location is the Gulf of Mexico. By race time we will have logged dozens of days, practicing each day for 4-5 hours. Team SubZero's challenge in testing is our commitment to allowing any student who wishes to be a pilot the opportunity to do so. With 13 new team members, many hours have been spent getting the students acclimated to the conditions of submarine racing and practicing their scuba diving skills. Our two returning team members from 2013, who will be part of the team again, will be put in a supervisory position as well as be divers and pilots

Every weekend last fall from August through October, and again, now this spring until the race date, the team will practice with the submarine. They will operate in about 5 ft. of water and critique and refine the sub's, and their own, performance. We do not practice in deeper water due to safety concerns that stem from not having enough well-trained support divers. Testing so far has revealed numerous issues that the students have resolved.

Measurements of air consumption under stress have been made. The air supply for each pilot has twenty to twenty-five minutes capacity depending on who the pilot is.

TRAINING

The SubZero 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 team members will be trained in each support position and we must have total interchangeability, because we change pilots every run.

PROJECT SUMMARY

Our goal continues to be to inspire students to pursue careers in STEM. SubZero 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 returning from the 2013 race. We will also have 4 former students serving in an organization capacity, who are now in college, the military, or careers. All the former students will attest to the benefits they have derived from participating in the ISR. These benefits range from increased personal confidence to a leg up in the college application process.

SubZero 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. The 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 SubZero 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.

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