

Old Saybrook High School

Jesse IV

International Submarine Races
Naval Surface Warfare Center
West Bethesda, MD
June 21, 2015

Introduction

Connecticut has had a long tradition of submarine design and construction, a tradition that continues today in Groton, where the world's most modern nuclear powered submarines are built. It was in the town of Saybrook, however, where in 1775 David Bushnell first launched what he referred to as a "submarine vessel," later known as the *Turtle*. Although its mission to destroy British warships was unsuccessful, the *Turtle* nonetheless represented the world's first vessel designed specifically for naval combat. More than two centuries later, students from Old Saybrook High school, under the direction of technical arts teacher Fred Frese, created a working replica of this historic "human powered submarine." On November 10, 2007, the replica was launched in the Connecticut River within sight of where Bushnell experimented with the *Turtle* more than 230 years ago.

With this same spirit of adventure and technological curiosity, Fred Frese and Gretchen Bushnell have compiled another team of students with the goal of rebuilding and racing a 21st century human powered submarine; for the 2015 International Submarine Races (ISR-13).

This manual is much more than an outline of information, procedures, and instructions regarding the incredible engineering feats and accomplishments of Old Saybrook High School's Submarine Team. This is a representation of hard work, determination, and creative innovation in building, maintaining, and supporting not only the submarine itself but our team as a whole. Moreover, this is a written, thoughtfully compiled, expression of the journey we have taken with Jesse IV, our human powered wet submarine.

Important Stats

Submarine Name	Jesse IV
Category	One person, propeller driven
Affiliation	Old Saybrook High School, Old Saybrook , CT
Academic Support	Pete Legnos, Gretchen Bushnell, Fred Frese, Allen Page Jerry Carlone, Ed Rosacker
Length Overall	11'
Maximum Diameter	28"
Displacement Wt. in Air	210lbs
Color	Black, grey, red
Propulsion System	chain drive-bevel gears
Team Leaders	Fred Frese, Gretchen Bushnell
Team Members	Alexis Bardos, Chelsea Weiland, Larissa Beecher, MaiLe Chaplar, Adam Burkhardt, Peter Blank, Carl Anderson, Ryan Bergeron, Clay Duffy, Peter Malinovsky, Megan Schulmeister, Ashley Malinovsky, Matthew Listorti, Keith Caron, Robert Andriozzi
Team Sponsors	LBI, Inc., Old Saybrook Education Foundation, Old Saybrook School District, Lou's Custom Paint, Diver's Cove, Jazzercise Fitness Center, Lion's Club, Lighthouse Signs, Whalen Engineering, Rolls Royce Marine Division

Team Objectives

Form a cohesive winning team

Redesign and rebuild a submarine that is balanced, buoyant, safe, and fast

Scuba certify the team by NAUI or PADI guidelines

Learn to work underwater using scuba gear

Learn how to design a propeller

Experience a variety of testing situations and conditions in the water

Learn to follow objectives and create goals

Successfully race the course

Have fun while learning real world skills

Educate the community about the ISR and our team's efforts

Our team comes from a small town named Old Saybrook at the mouth of the Connecticut River. We hail from a school of just over 540 students, 120 of which are graduating seniors. Our team is comprised of 12 students, five seniors, four juniors, a sophomore, and a freshman. Our team leaders are Mr. Frese and Mrs. Bushnell. We began development and recruitment during the early months of 2014 and have continued throughout 2014 and 2015 rebuilding the submarine, getting scuba certifications, designing the new propeller, and hosting fundraisers to help alleviate costs. We realistically realize our disadvantages against large engineering colleges and technical schools, but we firmly believe that our mission to undertake an international call for ingenuity and as high school students we will prove our commitment and potential.

Throughout the year, we have figured out ways to fully incorporate every student on the team and also assigned members to specific areas of research and development.

Throughout our presentation, multiple members of our team will speak about the specific topics they became familiar with.

This is Old Saybrook High School's second attempt at building and racing a one-person submarine. Our team is unique in that that majority of our school's course work is traditional college preparatory and not technical.

We are happy to have been invited back again to these races and have worked hard to measure up to the standards of the International Submarine Races. Thank you for inviting us.

Design

One of our goals is to successfully race our submarine with its modified hull, new hatch, and new propeller. We also redesigned the interior of the submarine to make the pilot more comfortable and adjusted buoyancy, reconstructed the dive planes and hatch. Lastly we reconfigured the front window for better visibility on the course.

Hull:

Early in the project, the design team from the 2011 team established the basic dimensions of a hull that would accommodate the largest individual among the students who had expressed interest in piloting.

The construction of our hull was a three-phase process. The first step was to build a "plug" that represents the outer surface of what will become the final hull. The second step was to form a mold over the surface of the plug. The mold was removed and the composite materials were then laid into the mold, forming the actual final hull. The plug, the mold, and the hull were each created in two halves. The hull halves were then bonded and strengthened along the seams.



Because of the potential hazards associated with the chemicals used in laying up the fiberglass hull, the school decided to assign the students the task of building the plug (see photos above). Mr. Legnos offered to build the hull at his facility. The educational opportunities associated with the hull, extend beyond the Old Saybrook students. Mr. Legnos and LBI Inc. are using the construction of the hull in an apprentice program sponsored by the state. The plug was provided to LBI Inc. and the mold created through this apprentice program. The students added provisions in the mold to accommodate the main and equipment hatches and the window. The molds were then returned to LBI where the hull layup was completed. The students then installed the drive train and other internal components.

Drive Train:

Propeller rotation is driven by rotary motion generated by the pilot through a bicycle crank. The crank rotation is coupled to a set of Curtis Machine Company Model 200M 1.5:1 bevel gears through a standard bicycle chain. The primary sprocket contains 30 teeth, while we have provided the option to select from three secondary sprockets with 13, 15, and 17 teeth. When coupled with the bevel gears, the total gear ratios available are 3.5:1, 3.0:1, and 2.7:1. Because we wanted to keep the bicycle crank centered in the vessel, it was necessary to mount the gearbox slightly off center. This keeps the primary and secondary sprockets aligned. We then included universal joints where the drive shaft connects to the output of the gearbox and where it attaches to the propeller bearing housing.

Propulsion:

The Jesse IV has a modified propeller designed by students from the previous race year with the instructional help from five engineers and designers from Rolls-Royce Marine Division. This original propeller was fiber carbon and it hadn't been manufactured correctly and fell apart in the last race series so a new propeller of the same student-design was manufactured through Diver's Cove. This new propeller has been manufactured to the specs of the previous one designed for the last race series. The Jesse IV also has a steel propeller as a backup. As required for safety, the propeller tips are painted red. The bow has also been modified. Several holes in the top have been plugged to allow for better hydrodynamics and hopefully, for greater speed.

Maneuvering and Control:

The joysticks will be used to control maneuvering including the rudder and dive planes. Jesse IV's dive planes were reconfigured to be smaller for better hydrodynamics. The rudder has remained the same.

Pilot Ergonomics

Pilot Position:

The pilot will lie in a prone position, facilitating a full view of the illuminated race course when underway. A wet suit will be worn as required for diving in water temperature that is expected to be below 65° F. The pilot will be weighted to ensure neutral buoyancy.

Shoulder Restraints:

The pilots will use shoulder restraints to push against when pedaling. The restraints are constructed to be adjustable to accommodate pilots of different heights. All current pilots have been measured to be sure to fit in the restraints safely.

Location of SCUBA Tank:

A standard 63 cu ft SCUBA tank is used. It is positioned in the aft section of the submarine.

Bicycle Cranking Rate:

We expect that the bicycle cranking rate during the course transit will be in the range of 60 to 75 RPM and possibly higher. This will likely vary between pilots. Testing of divers on a cycle ergometer at the Navy Experimental Diving Unit (see the NEDU reference in appendix A) indicated that a cadence of 45 RPM to 60 RPM would be appropriate for normal (aerobic) operations over an extended time. The brief duration of the 100 meter course, however, will enable the pilots to race at a much higher cadence. The mechanism adjusts to accommodate the size of all our pilots.

Bicycle Pedal Foot Restraints:

One of the volunteers is a long distance bicyclist, and had several suggestions for a pedal restraint that will not constrain the pilot in an emergency. We choose to use loose bicycle pedal clips to hold the pilot's feet in place.

Safety

Hatch Dimensions and Interior-Exterior Release:

The main hatch is side entry, 24" wide and 40" long, with a set of hinges on the top that hold it in place. The pilot will activate a quick release latch with a lanyard readily accessible near the window. An opening near the hatch will enable a safety diver to easily release the latch.

Deadman Release and Emergency Buoy:

The pilot will maneuver the sub with a right-hand-held joystick. The left hand will grip a standard bicycle brake lever connected through a cable to the buoy. The buoy

will be held in position by a spring that is released when the pilot releases the brake lever. The buoy line is wound on a fishing reel set to run free under the buoyant force of the buoy. It is located in the aft section of the sub.

Quick Release Waist Belt:

A standard quick-release belt, used by racecar drivers, has been installed so that it is readily released by the pilot and instantly accessible by the safety diver with the hatch open.

Strobe Light and Magnetic Lights:

A custom strobe light obtained from Whalen Engineering was mounted on the top aft section of the submarine. This light has been redesigned to work consistently under water. We are currently working on scheduling a design session with Whalen Engineering for us to design magnetic lights that will show the pilot if the boat is running neutrally.

Spare Air: This is a standard device that has been provided by Diver's Cove, a certified dive shop through which the team received our SCUBA training.

Testing and Training

SCUBA Qualification:

In the winter of 2014 and spring of 2015, a group of students on the team took classes in order to obtain scuba diving certification. Because anyone who wants to be a pilot or a support diver must be certified, a majority of the team has taken the class. We all went to Diver's Cove in Essex, CT. It requires six weeks of classes twice a week, both at Diver's Cove and at the Westbrook, CT YMCA. At the end, we had to perform several open-water dives to finalize the course. In June 2014 and 2015, we spent a weekend diving in Rhode Island, one day at Beach Pond and one in Jamestown. We went out in groups of three or four students with a dive master leading the way.

All students who will be pilots and support divers have completed their PADI SCUBA certification. The lead support diver will either be Ed Rosacker who is NAUI certified, or several of the volunteers who are qualified divers from Diver's Cove dive shop.





Propulsion System – Test Results:

The propulsion system of the submarine is obviously one of the most vital aspects when racing and achieving the maximum speed in the races. In the previous race, the team went with two blades off set at different angles after observing that with angling comes increased thrust and less pressure and torque.

By taking the average RPM that the propeller would move at (data observed from last years submarine team), the diameter of the propeller, and the velocity, we were able to calculate the final results. Equations, conversions, trigonometric functions, and integrals were used to discover the thrust and torque exerted by the propeller as well as the pressure water would have on it.

The mathematic model allowed us to quickly change the initial variables and see the impact they would have on the outcome. This allowed us to tinker with the numbers and once final dimensions were agreed on, we sent the numbers back to Rolls Royce where Jake Piskura created a 3D CAD image of the propeller. This CAD file was sent to the LBI Inc. where they used a 5-axis saw to cut the propeller out of a solid piece of material. The propeller was sent back to the high school where we attached it to the submarine. This propeller was not manufactured correctly and fell apart during our first race. It has been remanufactured with the same specifications for this year's races.

Submarine Operational Training:

We are hoping to test our submarine in a university pool in June. We will also use this as an opportunity to balance the weight of the sub and determine buoyancy for each pilot.

The pilots will be subjected to extensive safety and emergency procedures training. They will hopefully become comfortable with the process of entering the sub, settling into the shoulder restraints, waist belt and foot pedals, and then reversing

the order for a smooth egress from the vessel. Once comfortable with this process, the hatch will be closed and the pilots will all learned to adjust to the sensation of confinement. Since this is a new experience, it will be done in shallow water until each pilot is comfortable. They will also practice to follow an emergency procedure, including activation of the deadman release and emergency buoy, opening the hatch, releasing the waist belt and exiting the sub.

This operational testing will include procedures used in the race for launching and recovery. Two students (support divers) will support the vessel above the lake bottom. The pilot will be given the hand signal by the team's lead diver to begin cranking the propeller. At the end of the simulated race, the pilot will exit the sub and a group of student support swimmers will guide the sub on the surface back to the starting position.

Funding and Sponsors

- Rolls-Royce Marine Division- special thanks to Fred Pardis for organizing the design sessions
- Old Saybrook Educational Foundation- founded to encourage extra curricular academic opportunities.
- Diver's Cove- thanks to Ed Rosacker for his support and for lending SCUBA gear and teaching the PADI SCUBA course.
- Lighthouse Signs
- Lou's Custom Paint-thanks for the paint
- CEO of LBI Inc., Mr. Peter Legnos, has provided the essential design and construction of the submarine hull. With his help, and that of local submarine designer Allen Page, the students have gained sufficient insight into hull hydrodynamics to appreciate the impact of hull shape on their vessel's ability to efficiently transit through the water.

Closing

This project first started in the spring of 2013 when our teachers, Fred Frese and Gretchen Bushnell, started asking people to join the “Sub Crew”. When we first joined, we had no idea how immense this project would be. We started planning for the submarine and looking into scuba diving lessons and the project really took off. Throughout the experience, we expected to learn about engineering and scuba diving and the logistics of rebuilding and racing a submarine, but what none of us expected was that this would become a journey in which we learned about ourselves as well. As we went through the scuba training, we began to learn to be a team. We learned our own personal limits as well as our limits as team. We pushed ourselves to do things we had never done such as facing fears of being underwater for a long period of time. We also learned how to commit to a project and a team for a very long period of time. Throughout this project we have had to work through our problems, large and small, and stay committed to our goal, which is ultimately completing the races. We have learned how to work with people we have little in common with, in order to reach a common goal. We have also learned the basics of how to design a propeller. This journey has been more than building a submarine or even becoming a team, its become a true learning experience that none of us will ever forget.

Our Team

Alexis Bardos is a senior and is the captain of the team, as well as a pilot and dive support. She hopes for this years crew to beat the school's personal record speed at the 2015 races. She is also an honors student and long time member of the crew team.

Larissa Beecher, a support diver, is a senior at Old Saybrook High School. This fall, she will be attending Clark University and studying psychology. She plays the flute in the school band and in the orchestra for the winter musicals.

Adam Burkhardt is a senior. He is involved in the environmental club and will be a support diver for the team. Adam is attending Flagler College in the fall.

Chelsea Wieland-This is Chelsea's second race for our team. She is head mechanic and will assist with the ongoing maintenance of Jesse IV. Chelsea just graduated and will head to college in the fall.

Peter Malinovsky is going to be a senior and will pilot Jesse IV as well as provide scuba support. This is his second year on the team, but his first race. Peter enjoys computer science and mathematics and plans on majoring in one of these fields after high school. He also rows, plays basketball, and sails.

MaiLe Chaplar is a graduated senior of 2015. She is the manager of public relations, and a submarine pilot as well as support diver. This is her first year on team and she is absolutely thankful for the experience.

Carl Anderson will be a senior in the fall. He is a support diver and pilot. He also plays football and is on the track team.

Matthew Listorti is a 15 year old sophomore. He enjoys working on tractors, motorcycles, cars and about anything that moves. He also likes metal and woodworking and will be a mechanic for the sub team.

Ryan Bergeron is going to be a senior and is currently a pilot for our team's submarine. His older brother was a former member on the team which led to his interest in joining.

Megan Schulmeister is going to be a junior and will be pilot/support diver. Her hobbies include softball, drama club and spending time outside.

Clay Duffy is going to be a senior and he was on the team during the last racing series. He plays baseball and is also in the school band. He wants to go into the engineering field.

Peter Blank is also going to be a senior and he was on the team for the last racing series. His role on the team is life support. He is advanced PADI certified with nitrox. Peter hopes to be a pilot. He is also interested in engineering.

Fred Frese is a team advisor and the tech education teacher at OSHS. He was the builder of the original replica of David Bushnell's Turtle submarine and is the driving force behind this team. He was responsible for overseeing the outfitting and rebuilding the Jesse IV.

Gretchen Bushnell is a team advisor who was responsible for communication and logistics. She helped the students rewrite this manual and is a fitness trainer so one of her roles was to encourage the pilots to get in shape. She was also part of the propeller design team and a student evaluator in the project. She is also NAUI certified.