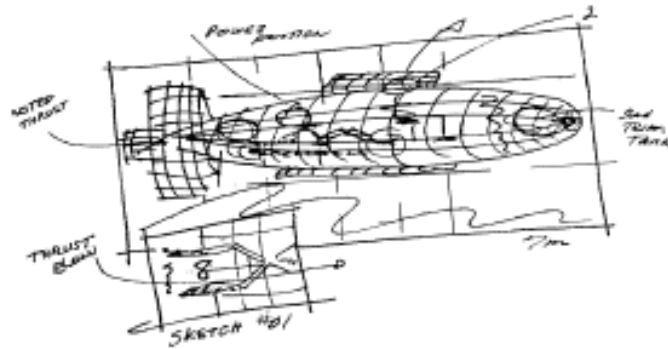


Final Design Report
Lone Star Concepts
“The Yellow Rose of Texas”



11th

**International Submarine Races
Year 2011**

Race Organizer – FURE (Foundation for Underwater
Research and Education)

Introduction:

Four guys from Waller TX decided to build a human powered vehicle, Keith, Daniel, Michael and Joe, to compete in the International Submarine Races, ISR 11. We intended this to be a Research and Design challenge and a chance to have an out of the ordinary fun experience.

Design Philosophy:

- Question everything: This was the overriding design criteria in our design and build efforts.
- This is a human powered vehicle race not a submarine race. It just happens to be the fluid media water.
- We evaluated all of the submarines from previous years and looked for the best features and ideas from each.
- Research each design feature to try to validate prior to inclusion in our design.
- We began with no preconceived ideas in creating our submarine design.

Design Assumptions:

- The pilot's physical position within the vehicle directly impacts the amount of power that can be extracted and utilized.
- Low available pilot power output requires efficiently applying this power to the propulsion system.
- The efficiency of the power transmission systems affects the torque that is available at the propeller.
- The weight of the vehicle components does not matter since the vehicle is neutrally buoyant.
- The vehicle volume is critical: the more displacement the vehicle has, the more difficult it will be to accelerate.
- The use of a tubular or cigar submarine shape as the primary structural feature severely limits the optimal placement, maintenance and utilization of all systems.
- The use of Commercial Off The Shelf (COTS) components simplifies the engineering requirements since the manufacturers have qualified component specifications.
- The ability to maintain, replace components and service the vehicle adds flexibility to adjust capabilities as needed.

- Utilizing the KISS (Keep It Simple Stupid) design philosophy will allow the vehicle to be less costly and more reliable.
- The use of solid modeling software will allow us to go from “art to part” with limited team resources.
- All safety requirements of ISR #11 will be designed in and installed.

Design Results:

- The use of a recumbent pilot position utilizing the arms, legs and back for power. (Fig 1)
- The use of an internally developed “Linear Drive” system. (Fig 2)
- The use of a welded frame with all propulsion and control systems attached. The hull is an attachment and not a constricting element to the design. (Fig 3)
- The use of commercially available drive train assemblies. (Fig 4)
- Minimizing displacement, even at the loss of hydrodynamic form. This will allow for quicker acceleration and top speed. (Fig 5)
- The use of additive manufacturing to create the hull surfaces, control surfaces and propeller nozzles. (Fig 5)
- The utilization of dual, counter-rotating ducted propeller assemblies. (Fig 6)

Design Research Validation:

- Research into propeller efficiency indicated that a shrouded propeller, over an open propeller, will have a higher bollard pull capacity of around 20%. Some sources quoted as high as a 50% improvement. Shrouded propellers are effective up to 12-14 knots. (multiple published sources)
- Research showed that the highest speed obtained by a Human Powered vehicle operating in the fluid air is a recumbent bicycle at 83 mph / 133 kph. (multiple published sources)
- The most common placement of propellers in vehicles that operate with air as their fluid media is an airplane with forward placed propellers. This places them in the calm air and allows for pulling the craft, rather than pushing.
- The effect of the pilot’s foot velocity had a significant increase in drag force, but minimal on drag coefficient values. ¹

- The leg angle between the calf and thigh where the largest force can be exerted is between 135 and 170 degrees.²
- The maximum force that can be exerted from a seated position at the angles described above is between 227 and 845 pounds.²
- With the use of a ducted propeller as a tractor, instead of a pusher, there is a considerable destabilizing of yaw.³
- The oxygen consumption at a heavy activity, sitting, is as high as 1.96 liters/minute and very heavy activity, sitting as high as 2.52 liters/minute.⁴

Design Verification:

- **Structural Frame and Hull**
 - To verify the interior volume, a physical volume study was done. Sections of the hull design were plotted every 6" and glued to 6" thick foam blocks. The profile was cut and shaped for each 6" foam block. The blocks were sandwiched together and clamped with removable clamps. The complete foam structure was split horizontally to create a top and bottom sections. (Fig 7a, 7b, 7c & 7d)
 - The design of the welded backbone frame was constructed out of dimensionally correct wood. This allowed the verification that the tube members were sized appropriately and the form factor was acceptable to all team members. (Fig 8)
 - The backbone frame model was placed in the lower half of the foam model and we evaluated the location of the linear drive system, gear boxes and the hull design. We found the linear drive assembly needed to move 6 inches forward and 2 inches lower. We found that there were areas of interference between the pilot and the hull shape. These interferences were noted. (Fig 9a & 9b)
 - The linear drive mockup was relocated and the foam re-contoured and the exercise was repeated. The space in the hull and the new linear drive placement was acceptable and ready for fabrication.
- **Linear Drive System**
 - A representative model was made using Additive Manufacturing, rapid prototyping, as a Proof of Concept for this internally developed design. It was manufactured at 1/4 scale. (Fig 10)

- Human Output Testing
 - We attempted to make a test bed to simulate the motion and action of the linear drive system. The test bed uses a ratcheted mechanism, mechanically linked to simulate the push-pull leg actions needed.
 - The testing would help determine the amount force we could push/pull in one stroke and how many strokes per minute. This would give us the usable power for a propeller design.
 - The linear drive system use is to slow down and minimize the number of strokes/minute. This will reduce the resultant increase in drag that occurs with a typical rapid pedal motion.
 - At the time of this report the findings are incomplete.

- Program Issues and Setbacks
 - We had intended to utilize Additive Manufacturing, sometimes referred to as “rapid prototyping”, to build the hull directly from the CAD model. We were given an early commitment by a service provider for that activity. That sponsorship was later withdrawn. This has forced us to build the hull by an alternative method.
 - The use of ducted propellers has caused some delays as there are no published design guides for this propeller application that we have found. This has made us depend on propeller design firms. So far we have had our assistance requests denied from three different continents.
 - The Human Output Testing equipment has proven to be unreliable. We are continuing to develop it to provide the best data for our propeller selection.

- Conclusions:
 - Successfully developed a Linear Drive System using reciprocating motion instead of bicycle pedal motion.
 - Completed a solid model of complete vehicle systems from “art” sketches that have been run through CFD (Fig 11a, 11b) and FEA simulations, fabricate parts from and build parts using Additive Manufacturing methods (rapid prototyping)
 - There are many new design features to integrate into both the acquisition and development cycle. This has created numerous slowdowns in vehicle build and completion.

Current Sponsor Participation

- DiveTech of Houston, TX provided SCUBA training for all 4 team members. They also are providing rental for equipment for the competition.
 - AnglGear, a group of Andantex, provided the miter gear boxes.
 - GoEngineer has provided SolidWorks design software and design analysis, CFD and FEA.
 - VersaBar has committed to providing travel expense funds and propeller acquisition.
 - Artech Manufacturing is providing machining and fabrication services.
 - Vision Manufacturing is providing manufacturing services.
 - R&M Energy Services-Tomball facility has provided engineering services.
- Citations for Research Data:
 1. Determination of hydrodynamic drag forces and drag coefficients on human leg/foot model during knee exercise: Poyhonen, T, Keskinen KL, Hautala A, Malkia E, Department of Health Sciences, University of Jyväskylä, Jyväskylä, Finland
 2. Pedal force-Limits Expectations: CT Morgan et al, "Human Engineering Guide to Equipment Design", McGraw-Hill Book Company, New York, 1963, pp 569, 570
 3. The ducted Propeller for STOL Airplanes, August Raspert, Aerophysics Department, Mississippi State University, State College, Miss., ASME, 1960, Studies conducted under the office on Naval Research Contract.
 4. Work, Heat and Oxygen Costs: P Webb, Bioastronautics Data Book (2nd ed, National Aeronautics and Space Administration), 1973

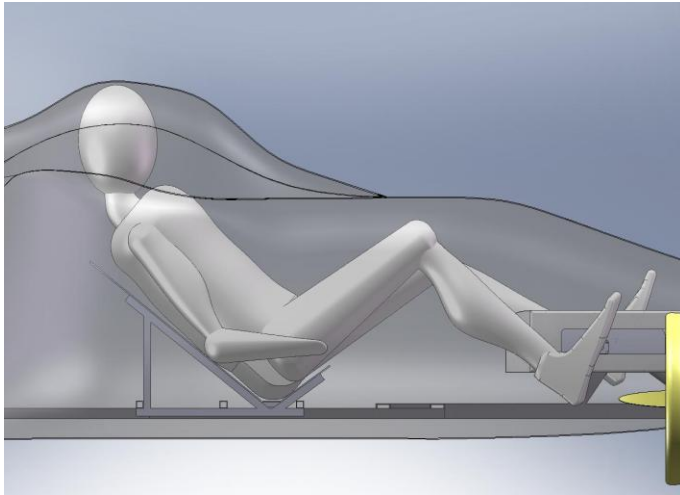


Figure 1 – Recumbent Pilot Position

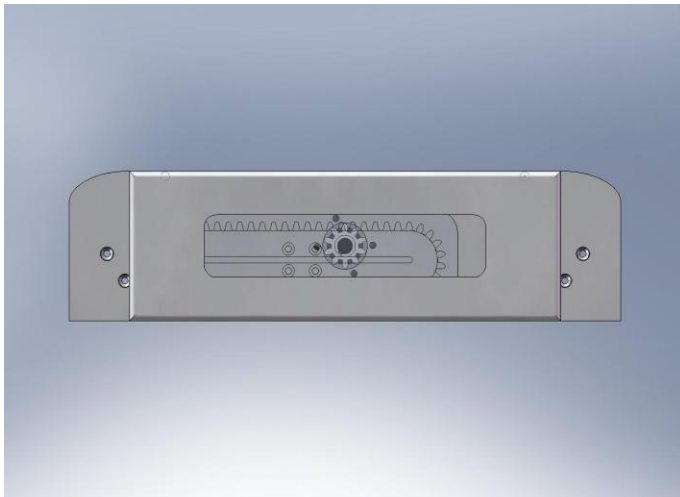


Figure 2a – Linear Drive System Showing Drive Rack

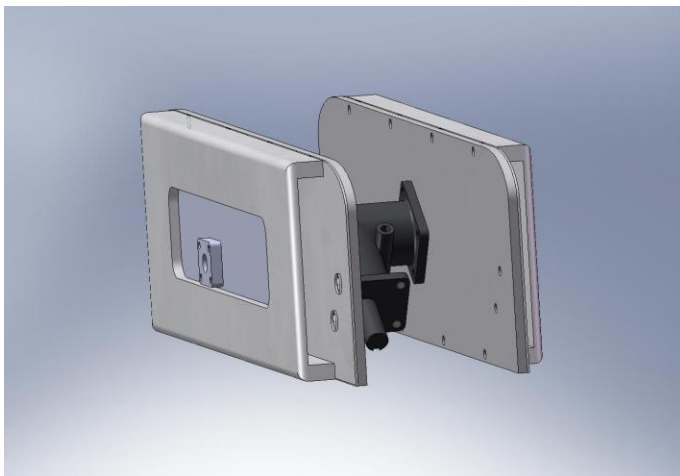


Figure 2b – Linear Drive System Showing Complete Assembly Design

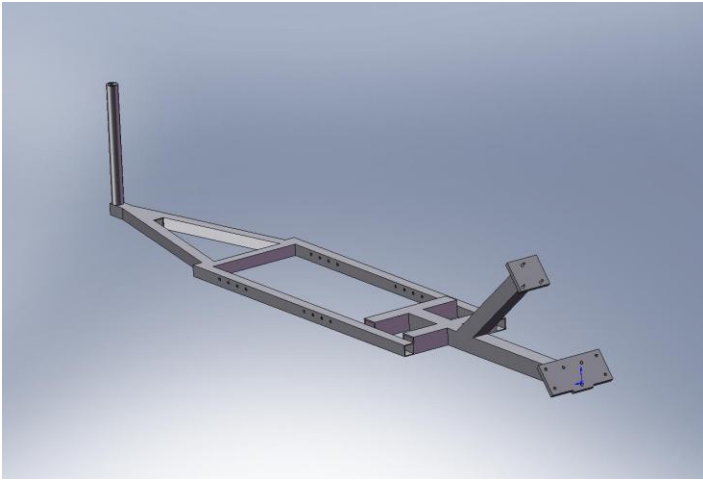


Figure 3 – Welded Frame for Propulsion and Control Systems Mounting

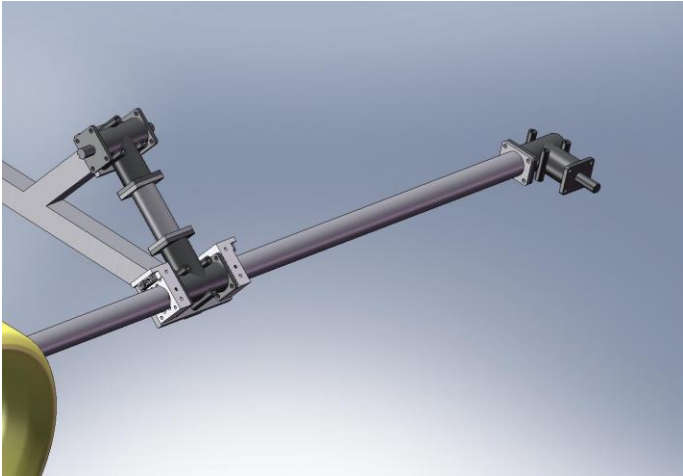


Figure 4 – The Use of COTS Components, Gear Boxes Shown This Figure

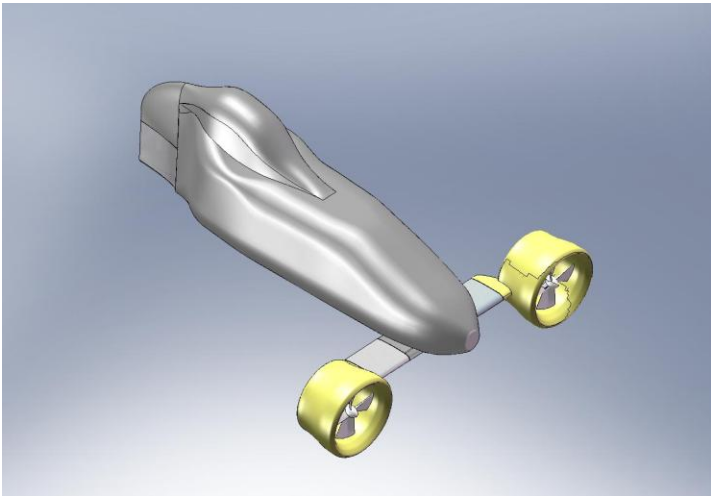


Figure 5 – Designed for the Use of Additive Manufacturing

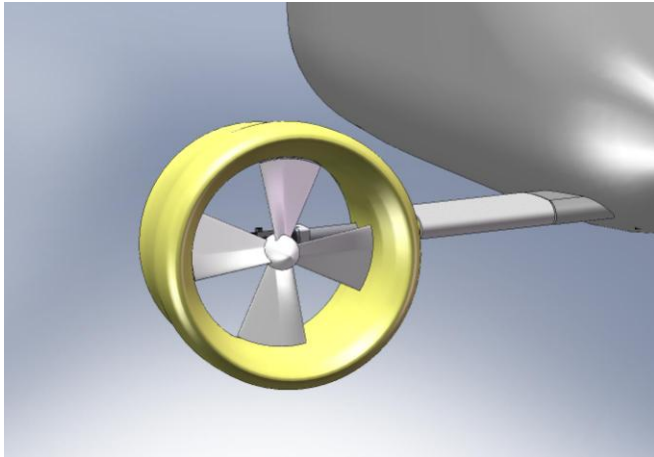


Figure 6 – Ducted Propeller



Figure 7a – Applying Computer Generated Sections on 6" Foam Blocks



Figure 7b – Cutting Foam Blocks to Pattern



Figure 7c – Fully Assembled Vehicle Interior Study



Figure 7d – Hull Split Horizontally Ready for Interior Space Study



Figure 8 – Structural Frame & Seat Mockup Placed Inside Foam Interior Study



Figure 9a – Team Member Evaluating Seat and Interior Space



Figure 9b – Testing Placement of a Mockup Linear Drive for Placement and Relative Leg Angle



Figure 10 – Linear Drive Proof of Concept Prototype – 1/4 Scale

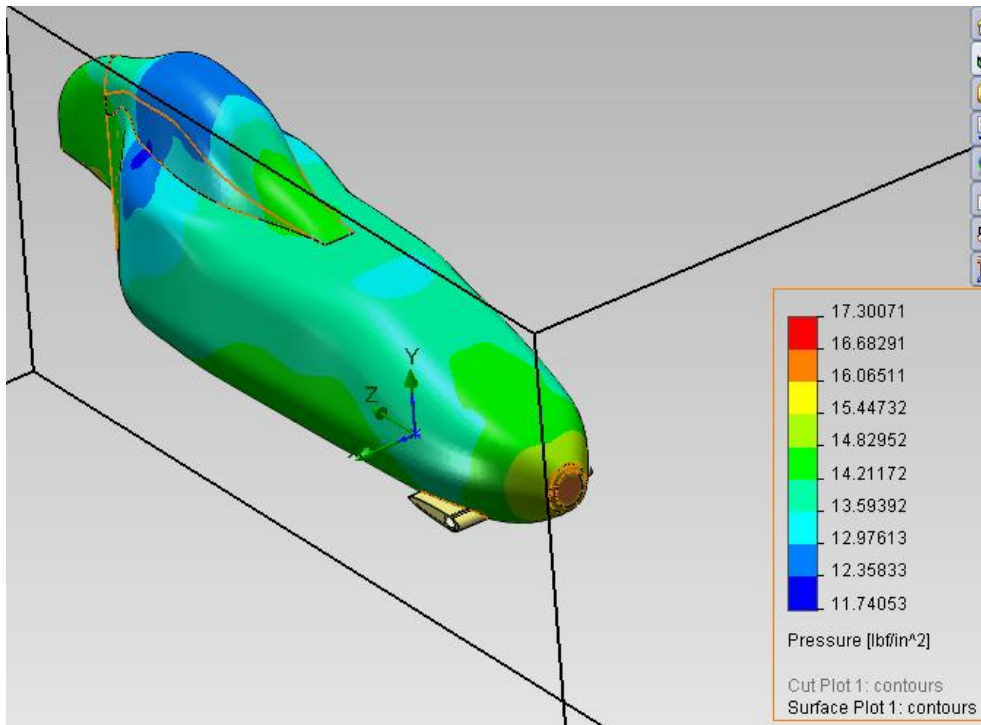


Figure 11a – CFD of Hull Design, Upper Right Quadrant

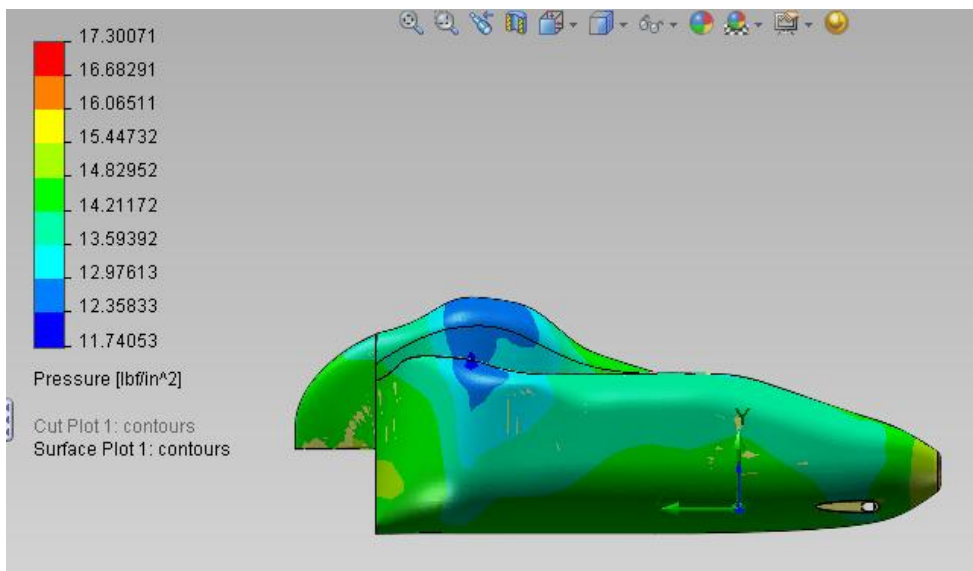


Figure 11b – CFD of Hull Design, Right Side