Talon 1

(One-Manned Submarine)

Florida Atlantic University

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Design Overview

The entry for the Florida Atlantic University One-Man submarine category will be employing the use of an existing hull that was used in the previous ISR race. The hull is a modified Gertler shape constructed out of a fiberglass and polyester resin matrix. The current hull shape has undergone computational fluid dynamic modeling to give quantitative results for the fluid forces acting on this particular shape. Modifications have been made based on these results, in particular the leading edge of the sub. Research and development has been done on the construction and implementation of a thermo molded polycarbonate nose cone. Through the CFD modeling, we hope to obtain a more hydro dynamically efficient hull shape.

Additionally, in part due to the CFD modeling, the steering and control surfaces are being re-vamped to be more efficient and ergonomically compatible with the submarine pilot. The control surfaces (rudder and dive planes) are being re-designed and fabricated to minimize drag as well as reducing their cross-sectional area, which in turn will reduce the possibility of over steering by pilots as well as reducing drag forces, both of these being hindrances to reaching the maximum potential speed of Talon 1. The mechanical steering controls are also undergoing re-development to make the submarine more “user friendly”. The upgraded controls will allow the pilot to maintain a current heading and/or make course changes as needed with relative ease and increase occupant safety.

Reuse of the old hull allowed the FAU team to save money on construction of a new hull. Since the focus of the submarine was optimizing the design, costs were minimal. The total cost incurred so far by the sub is about $140:

- Bilge Paint: $31.80
- Hardware: $2.38
- Polycarbonate Sheet (4x8): $75.00
- Bike Parts: $32.00

The technical design specifications for the FAU one-man submarine are as follows:

- Length Overall: 10.8’
- Maximum Diameter: 21” x 26” (elliptical)
- Displacement: 27 ft^3
- Weight in Air: Approximately 250 lbs.
- Propulsion System: Ring & pinion gear, two bladed propeller
- Steering System: Mechanical cable linkage, bow mounted pitch control surfaces and stern mounted rudder control surfaces
- Life Support: 60 cubic foot dive cylinder, emergency bailout, and constant pressure mechanical release “dead-man” switch.

Team Organization

The FAU Human Powered Submarine Team is made up of around 20 to 30 students. The number of members has fluctuated over the past two years, but at the end of the spring 2011 semester, the submarine team consisted of about 20 active members. The team is registered as a club on campus- Human Powered Submarine Club. Per FAU student organization rules, a secretary and a treasurer are elected every year. The club created additional positions such as Lead Engineer on one-manned sub, Lead Engineer on two-manned sub, buoyancy chair, safety chair, propulsion chair, etc.

The different positions encouraged people to take charge in an area but remain involved with both submarines. During the preparation for the 11th International Submarine Race, two members acted as lead engineers for the one manned submarine and another two members acted as lead engineers for the two manned submarine. All the other members were often active in the planning, construction, and testing of both submarines. The benefits of having a lot of people work on the two subs, rather than two separate groups, included learning from each other's mistakes and bonding more frequently as a team.

Fins

The fins were designed with the idea of minimizing separation and flow disturbance. They were designed using basic fin lift/drag theory, as well as incorporating a NACA cross-sectional shape. The NACA shape was decided on in efforts to reduce drag and obtain maximum lift. The lift equation used is based on infinitely thin foils.

Lift = $\rho A V^2$(0.5)(Coefficient of Lift)(Angle of Attack) **(1)**

Considering the symmetry of the wing over the chord length this was believed to be fairly accurate. A flat leading edge was believed to cause the flow over the wing surface to be more laminar, as opposed to a slanted leading edge and the eddies on the wing-tips that follow caused by the high pressure high velocity water pulling into the low pressure pocket behind the wing. However, the entire fins will be raked back 7 degrees in order to make their leading edges perpendicular to the water flow that is attached to the curvature of the hull according to CFD models (see figure2). This new angle should cause the fins to perform as originally planned. The MATLAB script for the fin design is included below as figure 1.

```
%input design parameters
%l= fin length in inches
% c1= base chord length in inches
% c2= tip chord length in inches
% need alpha to be +/- 8 degrees

knot= input('please enter velocity in knots: ');
length= input ('please enter fin length in inches: ');
base= input('please enter base chord length in inches: ');
tip=  input('please enter tip chord length in inches: ');
alpha= input('please enter angle of attack of foil (+/- 16
       degrees)\n(disreguard Drag for alpha > +/- 8 degrees): ');
knot2mpersec= knot*.514;

V=knot2mpersec;          %designed vehicle velocity [m/s]
ft2m= 1/3.28;
in2m= (1/12)*ft2m;
rho=1024;                %density of salt water [kg/m^3]
mu=1.3*10^(-6);          %kinematic viscosity [assumed] [m^2/s]

h=1*in2m;                % elemental blade thickness [m]
l=length*in2m;           %fin length   [m]
c1=base*in2m;            %base chord length [m]
c2=tip*in2m;             %tip chord length [m]
A=((c1+c2)/2)*l;         %fin area [m^2]

cL=1.2*alpha/16;         % lift coefficient
cD=.004;                 %drag coefficient (for alpha < 8 degrees)
R=(V*((c1+c2)/2))/mu;    %Reynolds number
lift=.5*rho*V^2*A*cL;
drag=.5*rho*V^2*A*cD;

fprintf('Lift %f N \n Drag %f N \n Reynolds # %e \n cL %f \n
              cD %f \n', lift,drag,R,cL,cD)
```

FIGURE 1 Fin design- MATLAB script

The rear fairings were designed with their upper most edge collinear with the upper most edge of the hull in order to keep the rudders out of the turbulence of the hull. They were designed in ViaCAD before a mold was cut out using the CNC machine, (see figure 3). The fairing mold will be modified to account for the 7 degree rake. The fairings will also straighten some of the turbulent flow in front of the propeller. The stationary fairings fight the moment caused by the lift generated by the rudder surfaces, however it was determined this may be beneficial for the straight line race in order to make minor corrections as opposed to high attack angles. After testing the maneuverability, the submarine demonstrated irregular steering patterns caused by fin stall and drag from over steering. So the conclusion was reached that these actions were not caused by the shape of the fin, but by its attack angle to the flow of water, which is not necessarily the direction the submarine travels. Also over-steering seemed to play a role in the patterns as well.

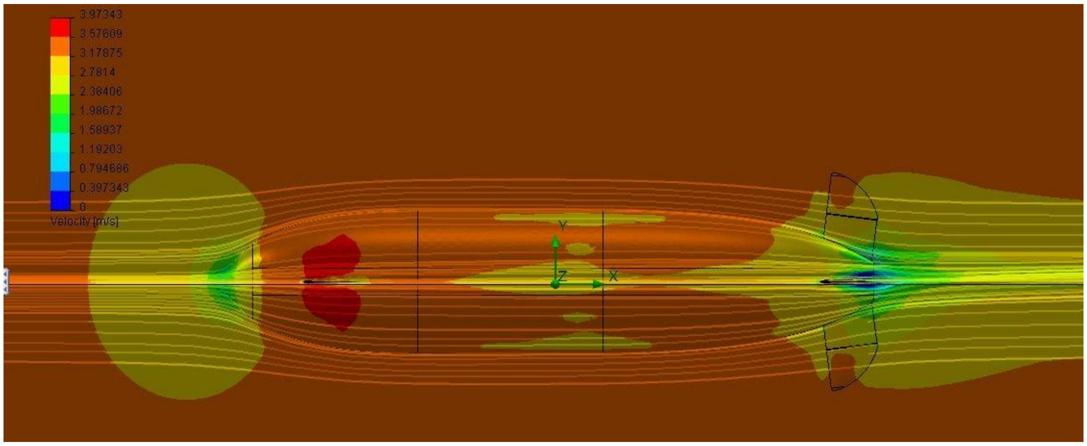


FIGURE 2.1   Side view of CFD model of Talon 1 with new nose cone and raked control fins.

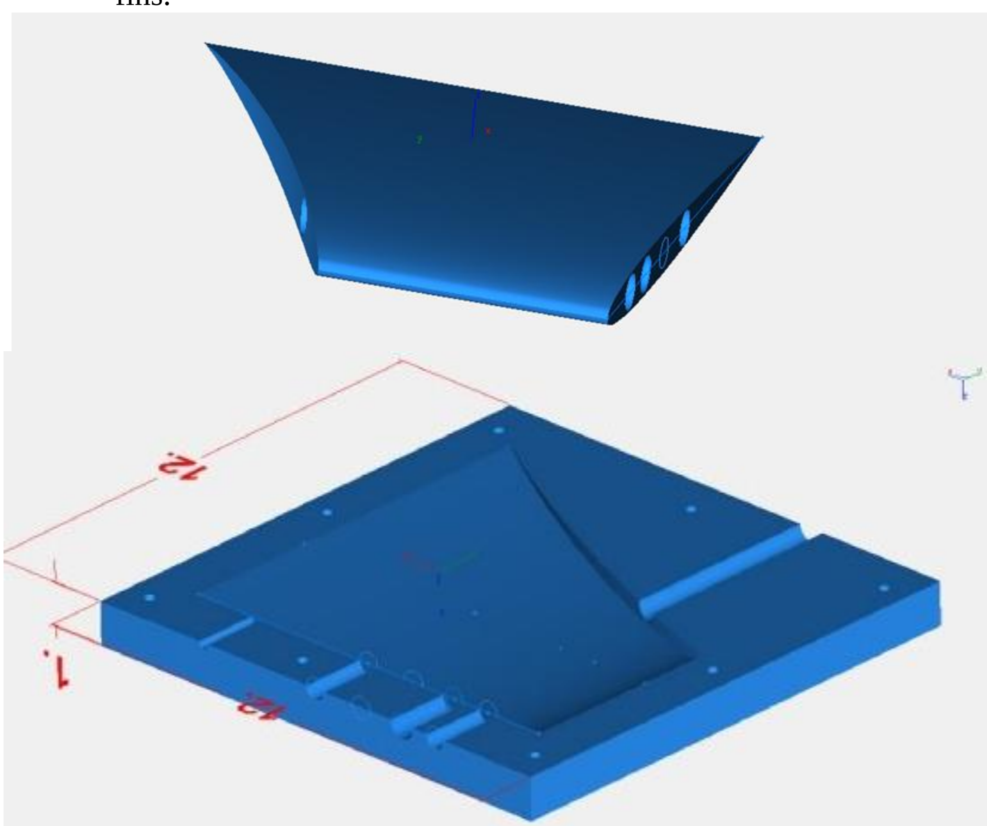


FIGURE 2.2   Top: Tail-fairing created in ViaCAD
Bottom: CNC fairing mold also done in ViaCAD

Hull

The hull design and sections were donated from an AUV to the team by FAU Sea Tech campus. Due to physical constraints, it was essential to acquire already fabricated hull sections. The initial design called for an elongated girdle shape, with an extended parallel mid body. However, after measuring several team members, making several CAD models of the hull and drive-train, it was determined that the diameter of the hull would be too small. Several alternative designs were subsequently modeled and reviewed by a FAU faculty member with experience in fluid dynamics. It was determined that one option, a longitudinal five inch spacer, would be the most practical solution.

Fabrication of the hull began initially by preparing the AUV hull surfaces and cutting the front hull section into four sections. Five inches was spaced out between the top and bottom sections to accept an aluminum band of the same size that would span the entire length of the sub. Before installation took place, the bottom two hull sections were fused back together. The aluminum band installed connects the top, rear, and bottom sections of the hull. An aluminum rib was fitted for the rear hatch support and acts as a universal mounting point. Finally, a Lexan cone was fitted to the front of the sub (see FIG. 3).

During the fabrication of the hull, fiberglass and resin were used to mate all section and spacers together. These materials match and mate well with the original materials used in the manufacturing of the AUV hull.

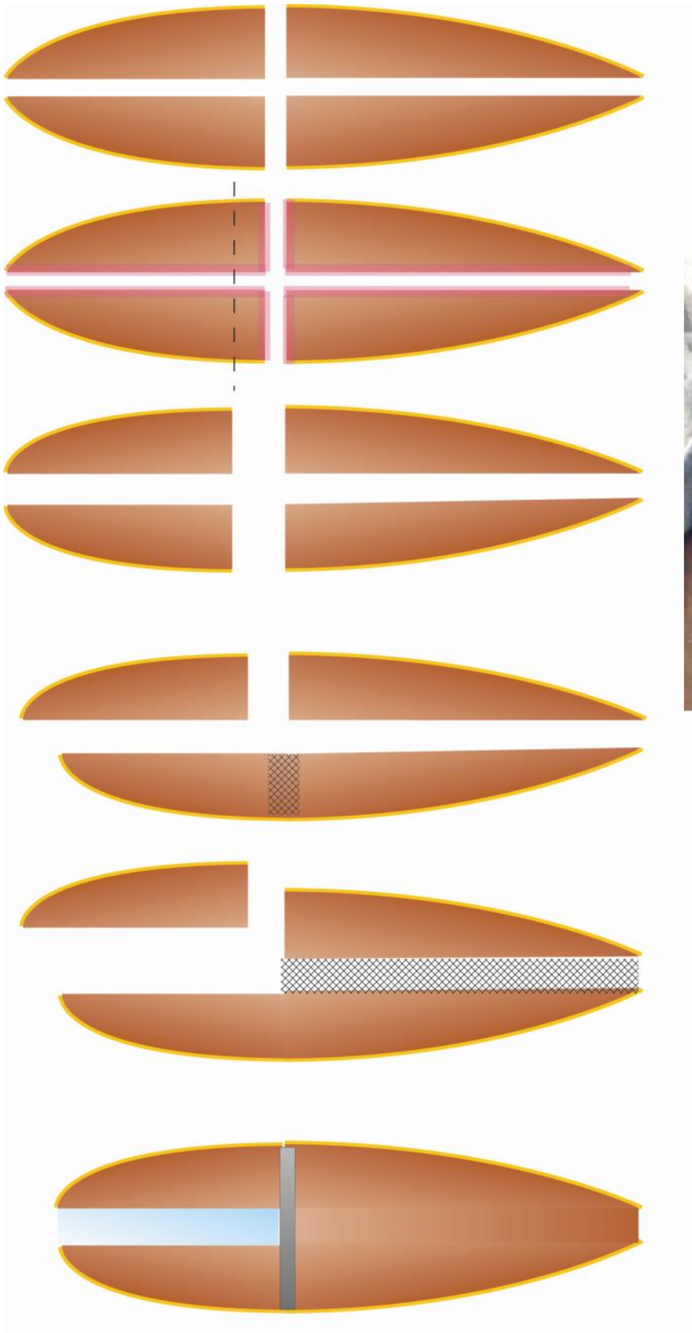
The main hatch of the sub was designed to accommodate most materials and divers. After calculating the pressure differential at our estimated top velocity, it was determined the structure of the hatch would have to be considerably reinforced as well as optimizing the hatch size. The pressure differential was found using Bernoulli's equations for incompressible fluid:

$$\rho A(dx/dt)\Delta V = -A(\Delta p) \quad \textbf{(2)}$$

The final hatch designs yielded, at 7 knots, a pressure differential of 1250 to 1290 lbs. on the main hatch, approximately 32 lbs. on the dead-man hatch, and approximately 58 lbs. on the rear access panel.

After the 2009 ISR it came to our attention that modifications to the hull design were necessary to further pursue the world record. Research and design of a new nose cone to improve fluid dynamics of the hull yielded a new design that when put through CFD modeling provided an estimated 6% reduction in drag. Coefficient of drag initially was around .0998 and with the new nose cone design it is dropped to .0939. In addition to decreasing drag, this modification is shown by CFD models to decrease flow separation along the hull and fins which may benefit overall handling of the sub (see FIG. 2).

The nose cone is manufactured from a thermo formed poly carbonate sheet of Lexan using a female mold. The female mold was used to get the perfect exterior finish and dimensions. The female was constructed from a MDF male of the new nose cone using tooling gel coat, fiberglass and resin. The new nose sits on a flange created when the old nose was cut to size. Existing windows were modified to integrate into the new nose cone. Overall, the nose cone improves forward visibility and testing at the races will validate the reduction in drag.



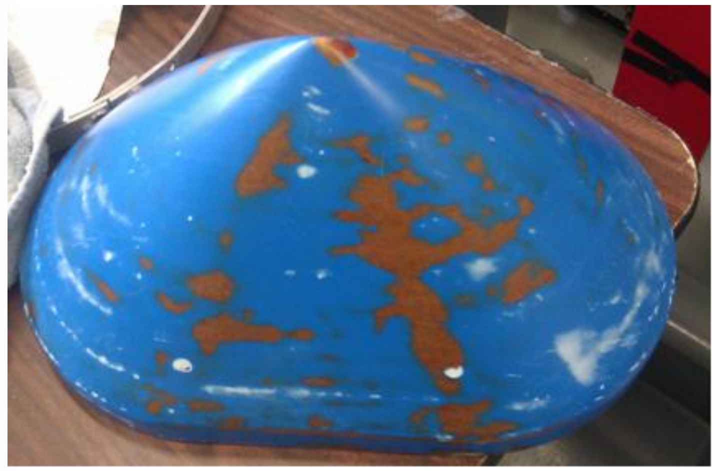


FIGURE 3.2 Nose Cone Mold

FIGURE 3.1 Fabrication of Hull

Propulsion

The *Talon* 1 is propelled by a 3 to 1 spiral bevel and pinion gear system. It has a custom milled gear box from a solid aluminum block. The gear system installed on the *Talon* 1 was recycled from the schools previous sub FAU-Boat.

Although the gear box and extension were recycled, a custom made mount was fabricated to fit our modified hull. The mount was designed using Pro Engineer and a CNC to mill the part. The mount was modeled to fit the curvature of the hull exactly. The mount is 14” long and the gear box extension is only 8”. It was designed it this way so that pilots could differentiate between 5’6” and 6’. There are a total of 13 different adjustments to allow exact placement of the driver if needed.

The *Talon* 1 has a direct drive shaft to the gear box. The shaft is attached to the gear box using a shaft coupler using hex head machine screws. The shaft is mounted to the rear of the sub with two mounting brackets, one on the inside and one on the outside. The brackets were also milled on the CNC to be tapered exactly to the 3D curvature of the tail. They are bolted together to create a crimping force as well as mounted to the tail of the hull. Inside these brackets is a plastic bearing mount that allows the bearing to spin smoothly.

The most important aspect of the *Talon* 1*’s* propulsion system is the two blade propeller. It is built from aluminum and crafted to a similar profile of an airplane propeller. It is approximately 22” long by 3” wide and has a 16 degree pitch to give optimal propulsion. This prop was selected from the collection that were designed and constructed in house. Through hydro testing, this prop yields the greatest thrust. The tips of the blades have been painted orange for safety. Since accurately testing the underwater speed capabilities of the sub is not possible, an estimate can be determined from data collected in the 2009 ISR and modification made since then. *Talon 1* achieves a top speed of 6.298 knots in 2009 and with modifications it should attain speeds of at least 6 to 7.5 knots.

Steering

Our original plan for the steering mechanism was to apply a one-to-one hydraulic system that would be operated with a joystick style hand control. However, too many complications were met with during the installation and testing processes. Taking the very tight schedule into account, we decided to move to our back up plan which would employ a cable operated steering mechanism. Fortunately, the cable system could be installed directly in place of the hydraulic system with almost no change in the rear mount for the rudder and just a bit of re-engineering at the front. This original system has been replaced with a new system that incorporates basic mechanisms from the original.

The new system uses a pair of brake levers to pull on either side of a converter lever. The converter lever allows the pulling of the left and right handles to push and pull on the specially fabricated rudder linkage at rear of the submarine. The horse-shoe shaped bend in the linkage allows the drive shaft to pass through unhindered and the arm extending from the bottom of the bend allows for increased leverage and more direct control over the angle that the fins can move through. The conversion lever also limits the effective steering angles of the fins from -10 to 10 degrees maximum of fin angle. Now the full motion of the steering system is utilized to the full effective motion of the fins. Limiting the steering allows more precise angle changes and minimizes the chance of over-steer.

In the front, the fins are operated by moving the steering lever either forward or back. The same system that controls the rudder is directly connected to the U-shaped linkage at the front of the submarine so the pitch is controlled by directly pushing or pulling of the front linkage by the steering handle. This new system is the same as before except the current set up uses bike cables instead of throttle cables that only operate on tension; these cables are much more flexible and make the pitch control a more flexible system.

Buoyancy

The buoyancy of the submarine is mainly created using pourable closed cell polyurethane foam. Since the sub is approximately 80 lbs. negative in the water, which includes the buoyancy created by the water displaced by the hull and all of the submarines components. According to Archimedes principle, the buoyant force on an object is the weight of the fluid that it displaces.

$$B=\rho Vg \qquad \textbf{(3)}$$

Therefore, in order to make the submarine 10 lbs. buoyant the foam inserts must displace 90 lbs. plus their own weight in water. The density of water is 62.43 lbs./ft^3 so roughly 1.44 ft^{3}of foam was used to create this buoyancy.

The volume was displaced by 2lb/ft^3 pourable polyurethane foam that was poured into different shapes and molds to make foam inserts large enough for buoyancy purposes but strategically placed to give the pilot ample room to operate the submarine and be rescued if necessary. The foam will be coated in a resin/fiberglass covering in order to make it ridged for mounting purposes and to protect the inserts from damages. The inserts will be mounted using an industrial Velcro that is adhered to the sub.

The sub was designed to be 10 lbs buoyant so that ballast can be used to trim the way the sub sits in the water. Since it is 10 lbs. buoyant, 10 lbs. must be used to make the sub neutral in the water. The advantage of having 10 lbs. to work with is the ability to trim. Also the foam is all oriented towards the top of the hull in an effort to raise the center of buoyancy, while the weight is placed on the bottom of the hull. This offset of buoyancy and center of gravity is designed to reduce torque roll and make the sub more stable in the water. Equally most of the foam is placed above the subs center of gravity in the same effort.

Safety

The tank used in the submarine as life support is an aluminum 60 SCUBA tank. When it is full, we can complete one run and still have two-thirds of a tank left of air. The hose used is 9 ft. long. It is a low pressure, wreck/cave diving, and second stage regulator hose. The sub also carries an emergency pony bottle for the driver in case of any failure.

The Dead man's switch is a system designed to save a driver if he becomes unconscious under the water. The system uses three inch PVC pipe to make up the housing for the buoy. The mechanism is a simple cable operated lever brake on a drum spooled with 31 feet of rope. The drum is held in place by the friction of an arm in tangential contact by the brake controlled by the pilot. A double spring system in series with the cable to the pilot will help create a buffer zone for dead man release in an effort to avoid unwanted release of the dead man buoys.

In an emergency situation, the driver will let go of the bicycle handle, (Dead man's switch). When released, the cable will release pressure on the arm and a spring aids in pulling away the arm, even though just the release of pressure would suffice. A previously cut out piece of the hull detaches and a buoy surfaces because the line is attached to a small pool buoy and then to the cut out piece of the hull. In the event of any failure in the cable or spring systems, the buoys will deploy as a failsafe, because the system is based off of constant pressure.

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