International Submarine Races

University of Monterrey

MAKO 1

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Executive Summary:

MAKO 1 is a single person, human powered, propeller driven submarine. The overall specifications of MAKO 1 are:

- Length – 3.5 meters
- Maximum Width/Height – 0.6 meters
- Hull material – Fiberglass
- Fins Material – Fiberglass
- Weight – 80 kg.

Our team's main objectives at the 11th International Submarine Race (ISR) are obtaining a minimum speed of 6 knots, successfully finishing at least 80% of the runs and being a formidable competitor at the race, possibly obtaining a speed greater than 7 knots, therefore competing with the winners of the 10th ISR.

In order to meet these objectives, the complete design and fabrication of MAKO 1 was required in a period of 6 months starting on November 2010 and finishing before June 2011.

Having no prior experience in the past ISR competitions or on submarine engineering and hardly any teachers with any experience on this branch of engineering MAKO 1 has been one of the most challenging projects that the department of engineering at University of Monterrey has attempted.

In the following sections a complete step by step of the different components, materials and efforts in the design and construction of MAKO 1 will be illustrated.

Our Team:

MAKO 1 team is composed of 7 undergraduate students from the departments of engineering and architecture. MaSc Gabriel Delgado Saldivar, CEO of one of our main sponsors MARECSA and our team supervisor and chief of the whole engineering department at our university Dr. Demofilo Maldonado.

Team Roster:

Team Supervisor: Dr. Demofilo Maldonado Cortes.

Place and date of birth: Mexico City July 6, 1970

Previous studies: PhD in mechanical engineering.

Phone number: +528182151260

E-mail: dmaldonado@udem.edu.mx

Team Advisor: MaSc. Gabriel Delgado Saldivar.

Place and date of birth: Zacatepec Mexico April 07, 1960

Previous studies: MaSc Hydrodynamics.

Phone number: +5219383860878

E-mail: gabriel.delgado@marecsa.com

Mechanical engineer student: Eduardo Palacios.

Place and date of birth: Nuevo Laredo Mexico December 15, 1989

E-mail: pa_lacioss@hotmail.com

Mechanical engineer student: Federico Martinez Ontiveros.

Place and date or birth: Mexico City February 02, 1987

Phone number: +5218182809019

E-mail: fmartinez19@gmail.com

Mechanical engineer student: Jesus Huerta Ovalle.

Place and date of birth: Monterrey Mexico October 18, 1989

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Mechanical engineer student: Ruben Salguero Garcia.

Place and date of birth: Poza Rica Veracruz Mexico August 20, 1989

Phone Number: +5217821629445

E-mail: rub_sg@hotmail.com

Mechanical engineer student: Roberto Mijares Guerra.

Place and date of birth: Monterrey Mexico August 30, 1989

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E-mail: mijares_roberto27@hotmail.com

Mechanical engineer student: Gabriel Delgado Ruiz Velasco.

Place and date of birth: Monterrey Mexico December 20, 1989

Phone number: +5218110505621

E-mail: gabriel_delgado9@hotmail.com

Architecture student: Veronica Treviño Villarreal.

Place and date of birth: Monterrey Mexico October 01, 1987

Phone number: +5218112143302

E-mail: verotrev.87@gmail.com

In order to complete the design and construction of MAKO 1, the team was separated into small groups responsible for different tasks and challenges.

- Hull
    - Federico Martinez
    - Ruben Salguero
    - Eduardo Martinez
    - Jesus Huerta
    - Gabriel Delgado

- Access Hatches and Fins
    - Federico Martinez
    - Eduardo Palacios
    - Jesus Huerta
    - Veronica Treviño
    - Gabriel Delgado
    - Roberto Mijares
    - MaSc Gabriel Delgado

- Drive System
    - Ruben Salguero
    - Eduardo Palacios
    - Gabriel Delgado
    - Jesus Huerta
    - MaSc Gabriel Delgado

- Propeller:
    - MaSc Gabriel Delgado
    - Antonio Del Rio (engineer at MARECSA)

- Gears and gear structure
    - Federico Martinez
    - Ruben Salguero
    - Jesus Huerta
    - Eduardo Palacios
    - Gabriel Delgado
    - Roberto Mijares

- Safety systems
    - Jesus Huerta
    - Veronica Treviño
    - Gabriel Delgado

- Divers
    - Ruben Salguero
    - Eduardo Palacios
    - Gabriel Delgado

- Submarine pilots
    - Gabriel Delgado
    - Eduardo Palacios

- Restraints
    - Ruben Salguero

- Computer modeling
    - Veronica Treviño

- Web page and picture administration
    - Eduardo Palacios

Due to the small group of people involved in the project and the short period of time, most people were involved in almost every area of the process of designing and construction.

Our organization

University of Monterrey is certified by SACS and several other educational programs, and has been teaching and inspiring young minds for over 40 years; the department of engineering has existed throughout this whole time offering different programs and opportunities to the engineering students.

Careers like Mechanical engineer and Industrial engineer have been offered for a long time acquiring vast amount of experience in the branches of materials engineering, process engineering and automated manufacturing.

The department of engineer and the shop at our university has always promoted manufacturing projects like the ISR, currently working on the SAE competition, MINI BAJA and super mile competition.

University of Monterrey won the 2011 ELECTRATON North Series, consisting on building and running electrical cars sponsored by TOYOTA.

Part of our Mechanical engineer curriculum, undergraduate students learn manufacturing techniques, material properties, advanced calculus, finite element methods, diverse physics courses, computer design and automated systems. Offering an extended yet profound amount of knowledge available to the mechanical engineer students.

University of Monterrey also offers various Master programs such as product engineering and industrial process engineering.

Our University also contributed to the budget of our project, acting as one of our main sponsors.

Sponsors

Being the first University in the northern region of Mexico participating in the ISR was not good in the matter of obtaining sponsors. Many organizations were not interested in supporting us due to the fact that most of them had never heard of this competition.

Still we were lucky to be supported by a few companies:

Veladoras Misticas is a medium size Mexican company; it has been operating for more than 17 years. It fabricates assorted candles, and sells them in the Mexican and American market.

Information:

Andres Guajardo 355

Parque Industrial Garza Ponce

Apodaca N.L. Mexico

Phone Number: +52(81)83863393

Maritima de Ecologia is a medium size Mexican company, operating since 2001 offering offshore services to PEMEX.

Information:

Calle 35 B 65

San Agustin del Palmar

Campeche Mexico

Phone number: +52(81)9383814690

Univeristy of Monterrey is a 40 year old university, is considered one of the best universities in Mexico.

Information:

Av. Morones Prieto 4500 Pte.

San Pedro Garza Garcia

Nuevo Leon Mexico

Phone Number: +52(81)82151000

TECNOR is a Mexican company that specializes in communications, offering services like SCADA, telemetry and automatic systems, around the globe.

Information:

Hilario Martinez 804

Col. Nuevo Repueblo

Monterrey, Mexico

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Design philosophy

The name MAKO 1 was inspired in the mako shark, being the fastest shark and one of the fastest animals in the planet.

Since we are the first team from our university to participate in this event, we had no starting point. We knew it was going to be a hard and challenging project and we had little time for building it.

Our team manager taught us a design technique that consisted in analyzing and evaluating different designs so we could choose the best one.

The first step in this project was to understand the ISR manual; by doing this we were able to mark the main restrictions in the design:

- The submarine had to be human powered, no stored energy is permitted.
- No decoupling devices were allowed.
- Full visibility of the pilots head was necessary.
- Store enough air for the race.
- Have a strobe light visible at 360°.
- Have a safety pop-up buoy.
- Attain neutral buoyancy at 22 ft.

After understanding the main restrictions and limitations, we followed the next design steps:

1. We separated the objectives, design and constructions steps into main categories and prioritized them:

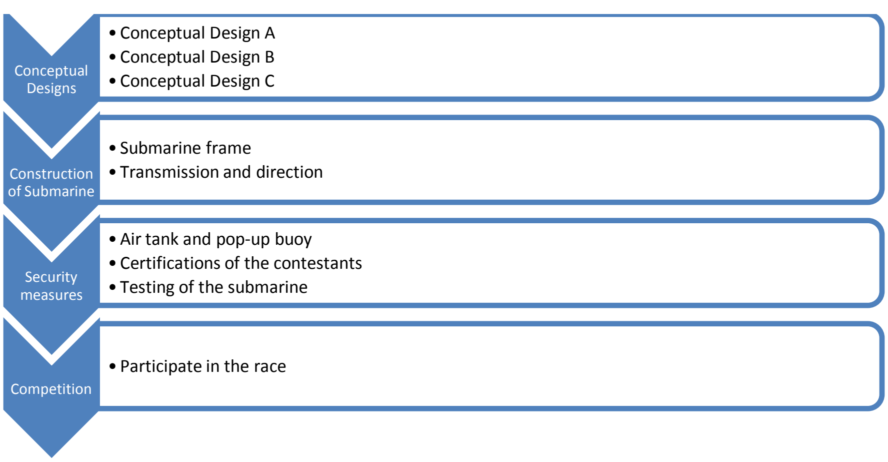
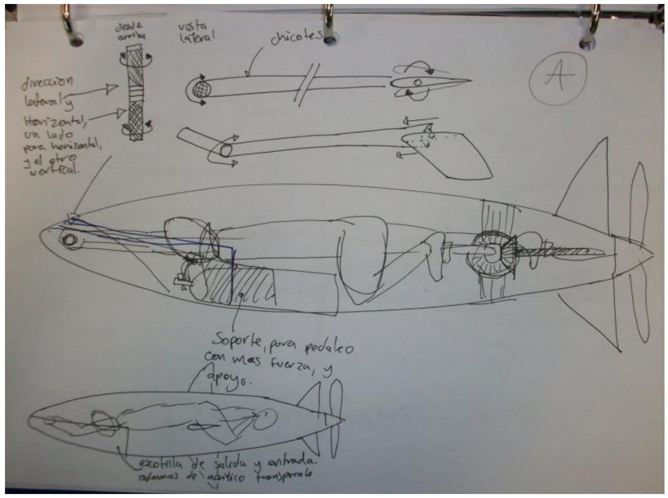
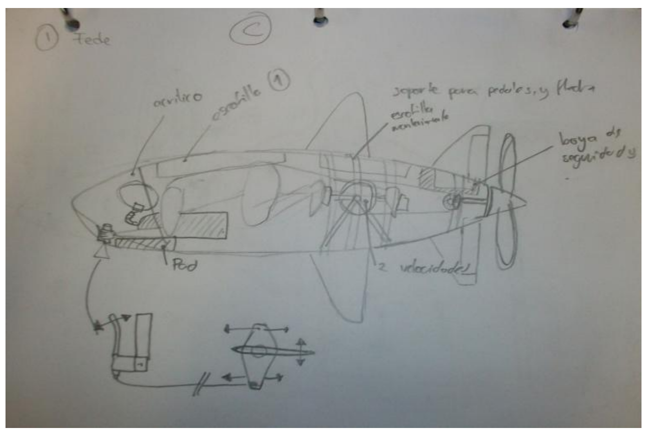


Image 1. MAKO 1 priorities.

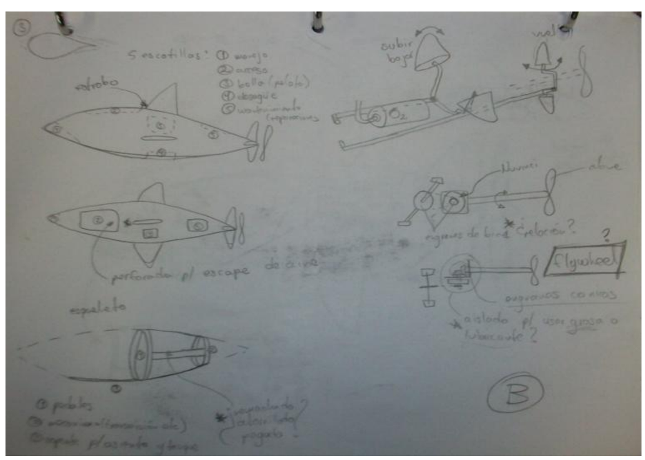
2. We came up with 3 conceptual designs that fulfilled the limitations provided by the ISR also specifying the main mechanisms and functions of the design:



Conceptual design A



Conceptual design B



Conceptual design C

3. After coming up with the main designs we fabricated an evaluation matrix, considering the aspects we thought of more importance for the submarine and using the next parameters and ratios:

Evaluation name	
Bad	1
Regular	3
Good	9

Importance		
Important	8	A
Very important	9	B
Indispensable	10	C

Evaluation Criteria	Parameter of evaluation	Relative importance	A	B	C
weight	Kg	8	9	3	3
Number of pieces	#	10	1	9	9
Facility of construction	A impossible B acceptable C good	8	3	1	9
Material Cost	$	10	9	1	3
Operation facility	A impossible B acceptable C good	9	3	9	9
Comfort	A impossible B acceptable C good	8	9	3	3
Accessibility	A none B little accessible C accessible	10	3	3	3
Security Factors	A none B fulfill	10	9	9	9
Driving facility	A difficult B regular C good	8	3	9	9
			439	429	513

Table 1. Evaluation matrix.

Multiplications were made between the relative importance and the grade that each concept of the evaluation criteria obtained, this way we were able to determine the best conceptual design, therefore having a starting point for the design of our submarine, our best option was our conceptual design C.

Design and Fabrication:

Hull

The model used for fabricating our submarine was obtained thru University of Veracruz, a former competitor in the past ISR. We were able to obtain one of the models they had used in one of the previous races and start from there.

Image 2. MAKO 1 model.

This was a huge advantage due to the small period of time we had in our hands, this way we had a volume margin and could start working on dimensions and how we were going to fit everything in the submarine.

Longitud	Diametro		Perimetro	Area (m2)			Area Proyectada				
m	cm	m		Entre Secc.	Total		Calculo de aletas				
-	-	-	-	0	0						
0.10	9.00	0.09	0.2827	0.0141	0.01		0.00	0.00	m2		
0.20	15.00	0.15	0.4712	0.0377	0.05		0.01	0.02			
0.30	20.50	0.21	0.6440	0.0558	0.11		0.02	0.03			
0.40	26.00	0.26	0.8168	0.0730	0.18		0.02	0.06			
0.50	31.50	0.32	0.9896	0.0903	0.27		0.03	0.09			
0.60	36.00	0.36	1.1310	0.1060	0.38		0.03	0.12			
0.70	40.50	0.41	1.2723	0.1202	0.50		0.04	0.16			
0.80	44.00	0.44	1.3823	0.1327	0.63		0.04	0.20			
0.90	47.70	0.48	1.4985	0.1440	0.77		0.05	0.25			
1.00	50.00	0.50	1.5708	0.1535	0.93		0.05	0.30			
1.10	53.00	0.53	1.6650	0.1618	1.09		0.05	0.35			
1.20	55.00	0.55	1.7279	0.1696	1.26		0.05	0.40			
1.30	56.50	0.57	1.7750	0.1751	1.43		0.06	0.46			
1.40	58.00	0.58	1.8221	0.1799	1.61		0.06	0.51			
1.50	59.00	0.59	1.8535	0.1838	1.80		0.06	0.57			
1.60	59.50	0.60	1.8693	0.1861	1.98		0.06	0.63			
1.70	59.00	0.59	1.8535	0.1861	2.17		0.06	0.69			
1.80	58.50	0.59	1.8378	0.1846	2.35		0.06	0.75			
1.90	56.50	0.57	1.7750	0.1806	2.54		0.06	0.81			
2.00	55.00	0.55	1.7279	0.1751	2.71		0.06	0.86			
2.10	52.50	0.53	1.6493	0.1689	2.88		0.05	0.92			
2.20	50.50	0.51	1.5865	0.1618	3.04		0.05	0.97			
2.30	48.00	0.48	1.5080	0.1547	3.20		0.05	1.02			
2.40	45.50	0.46	1.4294	0.1469	3.34		0.05	1.06			
2.50	42.50	0.43	1.3352	0.1382	3.48		0.04	1.11			
2.60	39.50	0.40	1.2409	0.1288	3.61		0.04	1.15			
2.70	36.00	0.36	1.1310	0.1186	3.73		0.04	1.19			
2.80	32.50	0.33	1.0210	0.1076	3.84		0.03	1.22			
2.90	28.50	0.29	0.8954	0.0958	3.93		0.03	1.25			
3.00	25.00	0.25	0.7854	0.0840	4.02		0.03	1.28			
3.10	21.00	0.21	0.6597	0.0723	4.09		0.02	1.30			
3.20	17.00	0.17	0.5341	0.0597	4.15		0.02	1.32	10% del area		
3.30	13.00	0.13	0.4084	0.0471	4.19		0.02	1.34	m2	8 aletas	cm2 c/u
3.50	13.00	0.13	0.4084	0.0817	4.28		0.03	1.36	0.136	0.017	170

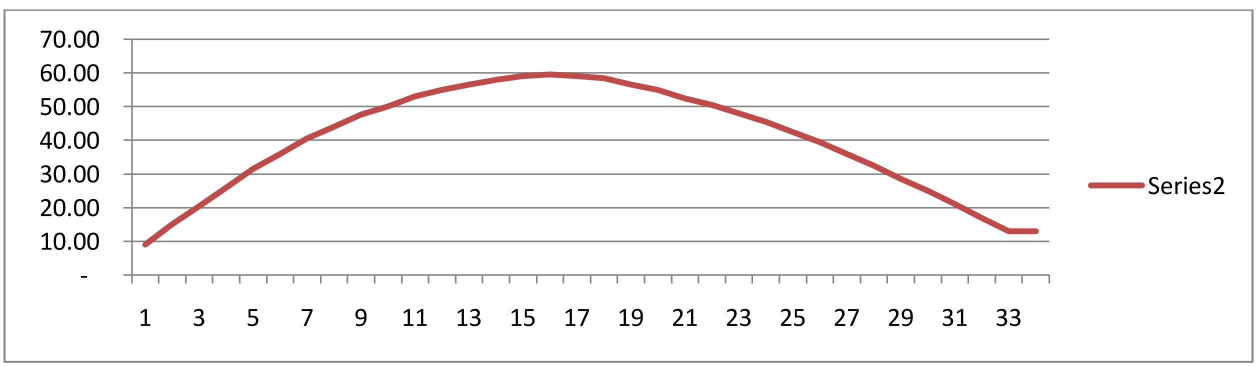


Table 2. MAKO 1 calculated area.

Measurements of the diameter were made every 10 cm. We then calculated the total cross section area of the submarine, which we would need for the design of the propeller, and the total cross section calculated was 4.28 m^2.

The hull was fabricated in fiberglass, using a total of 8 m^2 of fiber, one gallon of white gel coat; one can of molding wax and 2 gallons of fiber glass resin. As none of us knew how to use fiberglass, Professor Griselda from the department of Industrial Design taught us how to use it.

The construction of the model took a little over 6 days.

Image 3. Finished hull.

Both pieces were assembled together using fiberglass and a computer model was made with AutoCAD.

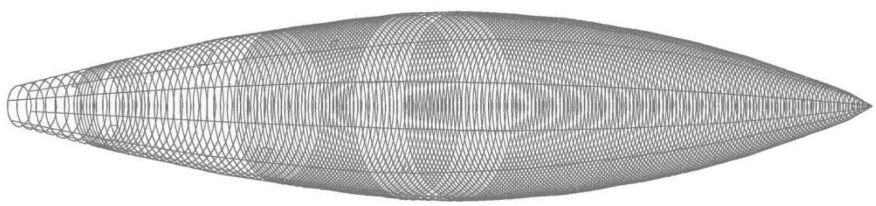


Image 4. Hull modeled in AutoCAD.

Gears and gear chamber.

The initial idea for our submarine was to eliminate the use of chains, chains are very friendly when installing them and maintenance is very easy but they have a disadvantage: they are not the most efficient drive mechanism. So we thought that using gears as in a car transmission was a very good idea.

The people in Veracruz also told us that they had used a 1:5 ratio for their submarine and had done pretty well. So we went a little further, the first ratio we intended to get was a 1:6.

We did the mechanical selection process and found a place where they could fabricate the gears.

Image 5. Gears.

The first option was to make them in steel, this option was discarded very quickly because steel gears need lubrication, they rust and their density is too high.

The gears were fabricated in a Nylon composite called Nylamil.

This material has several advantages to steel:

- It doesn't rust.
- Water lubrication suffices nylamil rotation.
- Density is very low.

The direction of rotation had to be changed, so the first set of gears with a ratio of 1:1 was set on the pedal gears and attached to our NuVinci transmition(this component will be discussed in another section of the report) with another shaft. In order to do this a gear chamber or structure was needed.

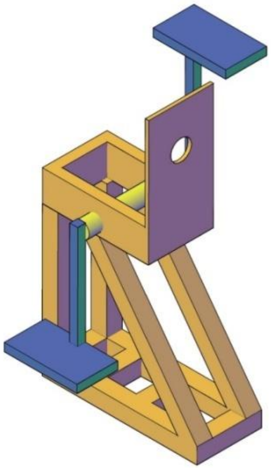


Image 6. Gear chamber modeled in AutoCAD.

The chamber (orange) was fabricated in steel and painted with antirust lead free primary paint. The pedal shaft (yellow) was also fabricated in 5/8´´steel rod and also painted with anti rust primary paint; it was fixed into the right position using two non rust steel bearings of the brand NSK. These bearings were fixed into place using customized bearing housing fabricated by the team. The blue components represent the pedals.

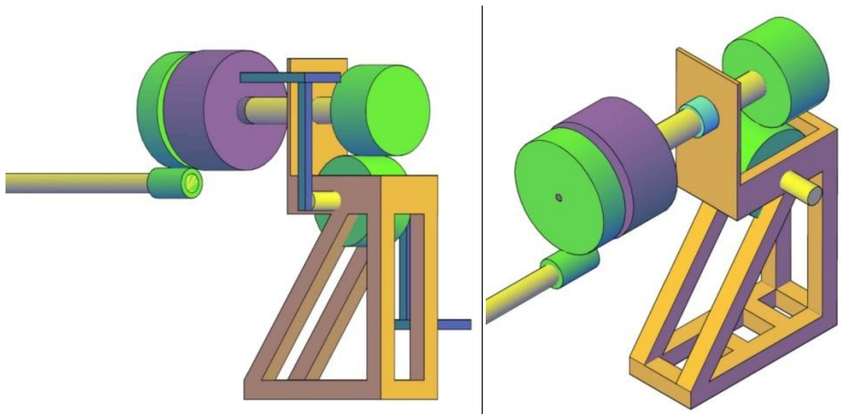


Image 7. Gears and gear chamber modeled in AutoCAD.

Gears are represented in green and the NuVinci transmition in purple.

After doing this, the gears were set into place. The first set were mounted directly into the pedal shaft (a) the direction change was possible because the gearing teeth designed are helicoidally arranged at an angle of 45°, giving us a 90° direction switch.

The second set (b) is two spur gears with a ratio of 1:5. These were fixed into the NuVinci transmition and to the propeller shaft using grade 8 screws.

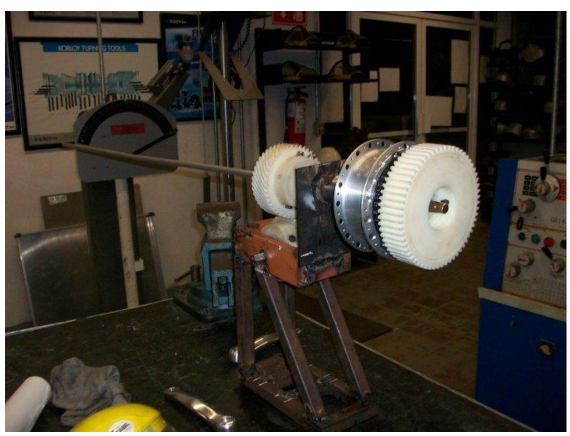


Image 8. Finished gear chamber with gears.

NuVinci planetary CVT.

Image 9. NuVinci planetary CVT.

This is the secret to what we believe will give us the winning edge on the race. During our design phase we considered using a transmition, the first idea was using a bicycle transmition but was discarded because we didn't wanted to use a chain. We then looked into CVT (continuous variable transmtions). We came to several discoveries, like the possibility of using a cone transmition with bands. Finally we discovered the NuVinci transmtion. First intended and already sold worldwide as a bicycle transmition, this mechanical device works similarly like the CVT's used in cars.

This transmition works with a set of balls inside a chamber, theses balls can be moved manually using a screw inside the mechanism changing the input-output relation between the driver and driven components.

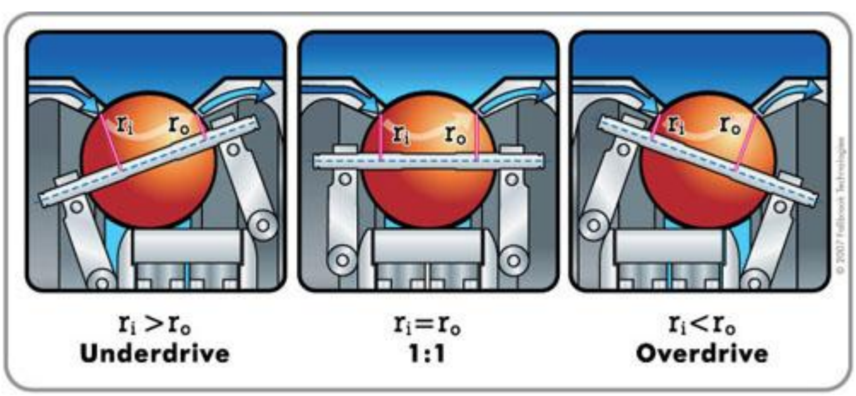


Image 10. NuVinci mechanism.

The greater the area of contact between the balls and the output disc the greater the speed is.

Being underwater breathing trough the mouth in a wet suit and in a small confined area can greatly affect the force generated by any human being. Propelling a submarine and defeating the stationary inertia of the submersible and the water, becomes a difficult task. The under drive feature gives us this advantage, reducing our initial 1:5 ratio from the gears to 1:2.5 making very easy to "start our engine" and break the inertia generated by the water.

In small words this component acts like an automatic transmition, modifying our gear ratio from 1:2.5 to 1:9.

Drive system.

The system for driving the submarine is quite simple, since the submersible is a wet submarine and buoyancy depends on the inner density of the submersible, our main concerns are yaw and pitch control.

Yaw control: to control this we attached two fins to a set of 5/8´´ steel bars that cross the back part of the submarine, they act as rudders and help maintain the submarine from going to the sides and possibly crashing into a wall.

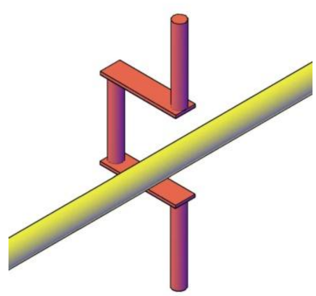


Image 11. Yaw control modeled in AutoCAD.

The yellow bar represents the propeller shaft and the pink piece represents our yaw control system. This system will be controlled using bicycle cables from the front of the submarine.

Pitch control: this was obtained by installing two fins to half of a steel circle in the front part of the submarine.

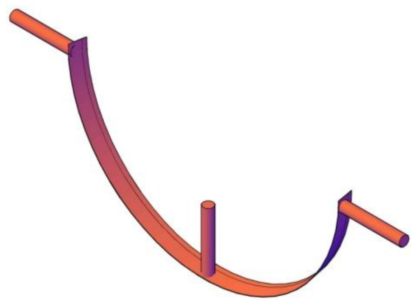


Image 12. Pitch control modeled in AutoCAD:

By moving this component we are able to control the pitch. The yaw control was mounted in the middle bar as shown on image 13.

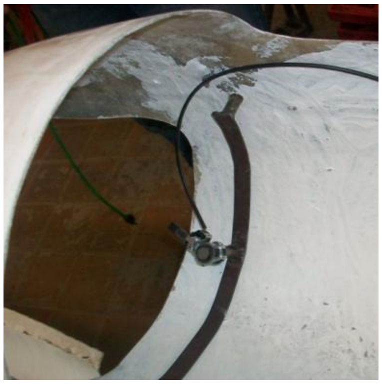


Image 13. Yaw and pitch controls.

This way everything is controlled by one hand having the other free for the safety buoy.

Fins.

The fabrication process of our fins was very similar to the one used in surf boards made by hand from low density foam, covered in fiberglass and giving them the final detail with polyester. 5/8´´ holes were made to the base of the fins in order to assemble them to the drive systems.

Image 14. Actual fin.

Propeller.

The propeller for the submarine has not been finished, although is now in construction we will show in the next section how the best design was acquired.

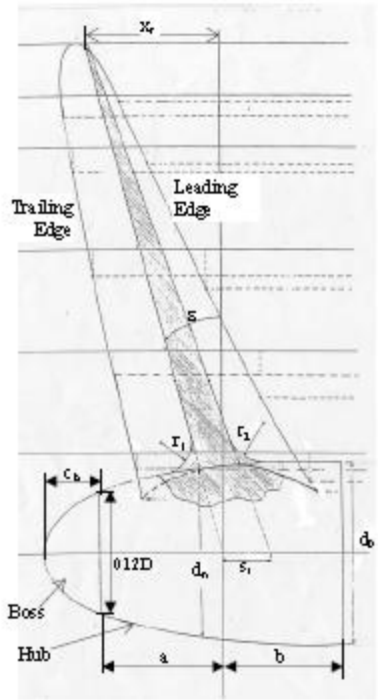
The first step in designing the propeller was calculating the area and the approximate speed outside the water.

Having these factors and using texts in design of propellers, we were able to come up with the best design.

Using the factors and the characteristics already mentioned in the past sections and a speed of 240 RPM (lower than the actual speed).

We acquired the next factors for the design:

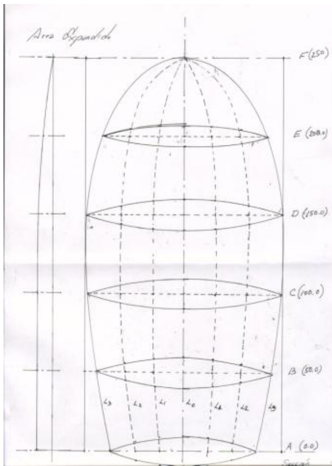
D	0.3	m
dn =	0.0501	
do =	0.054	
r1 =	0.009	
r2 =	0.012	
s1 =	0.015	
s1´ =	0.00105	
s1´´ =	0.00045	
a = b =	0.0375	
xr =	-0.04019238	
Cb =	0.03375	
dh =	0.036	



The final outcome of the propeller is roughly 30 cm. In diameter, since the speed used is lower than the real one we decided to make the propeller slightly larger, approximately 50 cm in diameter, this way we will avoid cavitations and have better results due to the higher speed.

Actual propeller design:

Seccion			L0	L1	L2	L3
	Ancho	Altura	Espesor de la pala (mm)			
A	93.7	0	9.5	7.9	4.8	0.0
B	112.7	50	9.5	7.9	4.8	0.0
C	123.8	100	9.5	7.9	4.8	0.0
D	123.8	150	9.5	7.9	4.8	0.0
E	106.4	200	6.4	5.3	3.2	0.0
F	0.0	250	0.0	0.0	0.0	0.0
			L0	L1	L2	L3
			Distancia a eje central (mm)			
			0.0	15.6	31.2	46.8
			0.0	18.8	37.6	56.4
			0.0	20.6	41.3	61.9
			0.0	20.6	41.3	61.9
			0.0	17.7	35.5	53.2
			0.0	0.0	0.0	0.0



Safety systems.

Several safety features had to be done according to the ISR manual, the first is having a strobe light visible at 360°, visible at one mile outside the water and a frequency of at least one flash per second.

(a) (b)

Image 15. (a)Strobe light, (b)safety buoy.

The strobe light used in MAKO 1; it has a 1 flash/second frequency it is visible up to two miles and will be installed on the roof of the submarine.

The next safety measure was the pop up buoy, our system will work using the brake of a bicycle, holding the brake will keep a hatch close and in the event of an emergency the brake will be released, the hatch will open and the safety buoy will ascend to the surface. A 10 meter fluorescent cord will be attached to the buoy.

The buoy is a fishing bobby (Image 15b) enhanced with an orange light.

Access hatches.

Four hatches were made for the submarine, the main and pilot access hatch had to be big enough for the pilot to access and exit the submarine very easily.

A second hatch was made where all the mechanical components are, making it easy to fix or give maintenance to anything that might go wrong regarding the mechanical components.

A third hatch was made where the polycarbonate glass will be mounted. And the fourth and final hatch was made for the safety buoy.

Image 16. Access hatches.

Restraints.

A chest mount was fabricated to support the pilot and lifting him from the floor of the submersible giving him the right height to successfully pedal the submarine. The space between the structure is big enough to hold the O_2 tank.

Training

In order to comply with the ISR manual that states that all people that go in the water must be certified as a scuba diver.

The main pilot Gabriel Delgado was certified in April 2011 in Houston Texas.

The other two divers Ruben Salguero and secondary pilot Eduardo Palacios, will be certified at the end of May of 2011 in Tampico Mexico.

Both pilots have been training physically for the challenge, including several sports like, swimming, running, stationary bicycle, tae kwon do and cross fit.

Testing

Several tests were made:

1. Speed outside the water: 300 RPM average.
2. Buoyancy Test: Successful, the submarine is negatively buoyant but will be compensated with flotation.
3. Safety Buoy: Successful.
4. Speed inside the water: Has not been tested yet due to the lack of a propeller.

Budget and Finances

Most of our budget was covered by our sponsors; nevertheless the team had to pitch in to cover the full expenses.

	Sponsor paid (usd)	Team paid (usd)
Gears	460	0
Fiberglass components	350	0
Steel tubes and frames	120	0
Pedals	0	15
Model shipment	130	0
Bycicle accesories	15	0
Propeller	680	0
Polycarbonate shield	70	0
Safety systems	60	10
Training	1150	0
Tools	100	50
Scuba rental for tests	100	20

Assorted materials	80	20
	3315	115

The values shown are an approximate to the real cost, we took the exchange rato of 11.80 Mexican pesos for one American dollar.

The travel expenses have not been taken into account since will be driving to Bethesda.

Photo Journal.

Conclusion.

A lot was learned in the process of this project. Some of us didn't know how to use machinery, tools and fiberglass, didn't know how to weld, how to make holes for a screw. Blood was shed, screams found their way in our shop, jokes were made and laughs filled the room where we worked. The truth is, all of us didn't know what we were getting into.

At the start it sounded like fun, "hey we´ll get it done in 3 months and test it". "A submarine? Piece of cake". These were some of the things we said or thought. We also heard comments from teachers and friends like "You´re not going to make it", "You're not going to be able to finish it”, “You won’t get the money”. We had our spirits down but we never stopped and just a few days from finishing the submarine and having the resources to go to the race, we are able to say “WE MADE IT”.

MAKO 1 is the first breed of submarines in our University, although it was designed and constructed in less than 6 months, we built a wonderful machine, definitely a great addition to our University´s curriculum and most definite a great experience for the team, not only we learned how to handle different chemicals and tools. We learned how leadership affects in a team, how to get money (one of the hardest parts in our project), how to talk to people, where to buy and fabricate things. We also learned that any time in a project can change in the last second affecting the outcome of our plans, but with a little determination and patience everything works out fine.

In the end we can say that this project is a success, and in order to finish anything you have to mean it, not only is this an engineering challenge, this a challenge of spirit, mind and body.

We believe MAKO 1 will be a strong competitor in the 11th ISR and will be the starting point of a new engineering generation at our University.

Special Thanks

Thanks to our sponsors, Maritima de Ecologia, TECNOR, University of Monterrey and Veladoras Misticas, you are the ones who brought this project to life.

Thanks to all our teachers that showed even the slightest interest in the project, providing us with their knowledge and time to help us. To Dr. Demofilo Maldonado who agreed to the making of this project, to our design teacher Faustino Garcia who helped us with the modeling of our propeller, to our industrial design teacher Griselda Villarreal who taught us how to use fiberglass and to Luis Alberto Carreon the mechanical shop supervisor whose patience brought MAKO 1 to life, thank you so much to all of you.

To all our friends and family members that helped us by cheering and motivating us to give it our best and finish successfully in such a small period of time.