Universidad Pontificia Bolivariana

1st International Ship Design & Naval Engineering Congress

March 25 - 27, 2009
Cartagena de Indias, Colombia

COTECMAR

Simulation of the thrust forces of a ROV

Juan A. Ramírez
Luis B. Gutiérrez
Manuel García
Raúl Valencia

Automática y Diseño

AUTOMATION & DESIGN A+D
http://amasd.upb.edu.co

Scope of this study

•This thesis presents a computational and experimental study of the physics that governs the submergible vehicles.

• In particular drag and thrust forces, and structural analysis are accomplished with the objective of optimizing the design of a ROV prototype.

•This study also aims to consolidate methodologies of multidisciplinary investigation that link the analysis and design.

Outline

- Introduction
- Thrust forces and Propeller
- Drag forces
- Structural analysis of dome
- Other products
- Conclusions

Introduction

Ocean technologies

With the objective to explore in and make tasks in aquatic environments, the next technologies have been developed:

- Laboratories
- Submarines
- ROV
- AUV

Aquarius station. Work depth: 20 m. Located in Florida

JOHNSON-SEA-LINK

TIBURON ROV

Autonomous

BENTHIC EXPLORER

ROV (Remotely Operated Vehicle)

•ROV (Remotely Operated Vehicle): submarine operated through an tether cable for communications.

•They have been used for surveillance and maintenance tasks in different fields such as: port industry, military industry, oceanographic research, aquaculture, marine biology, etc.

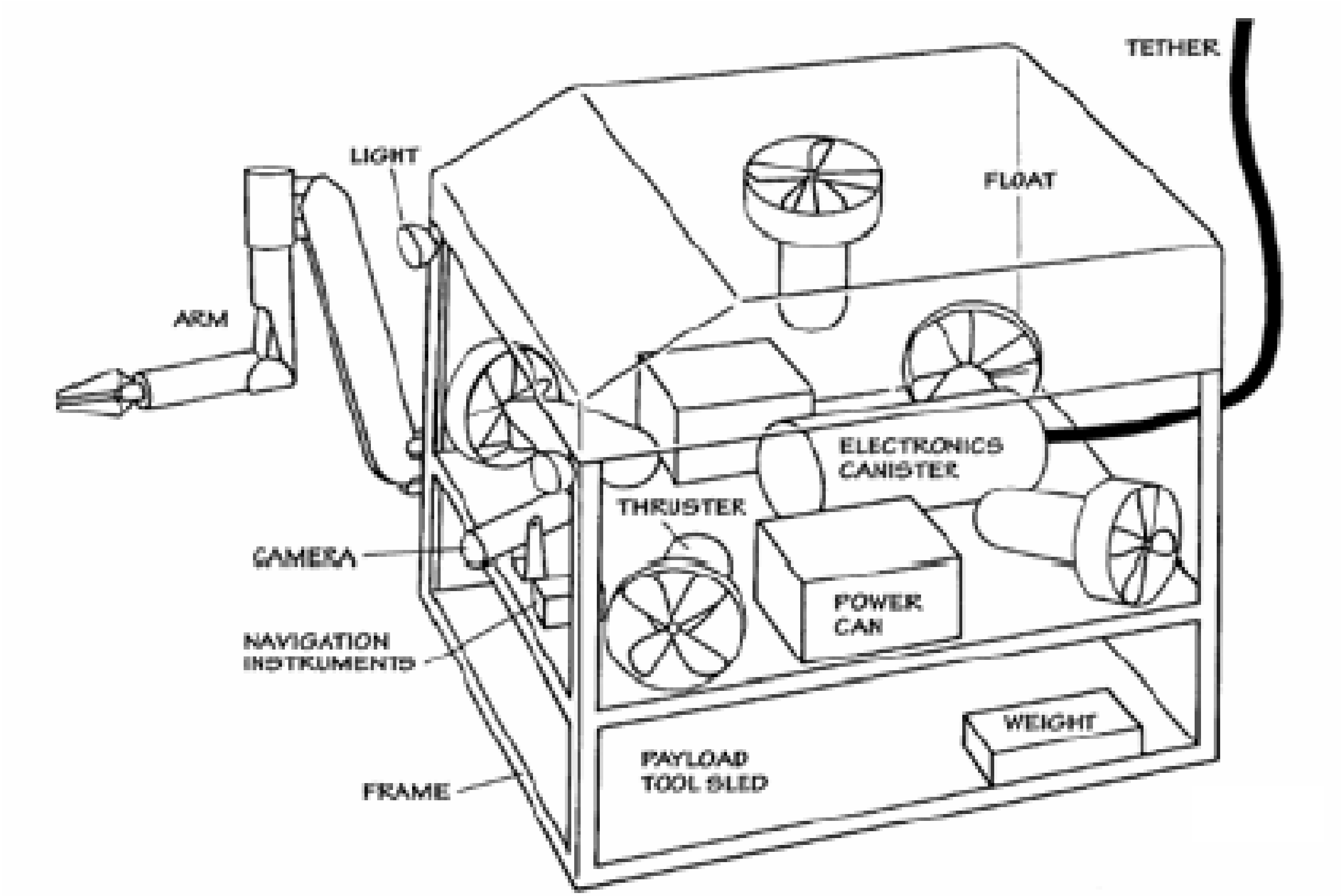
•This kind of vehicles could be classified in three main groups: heavy work, observation and micro/mini ROVs

HEAVY WORK

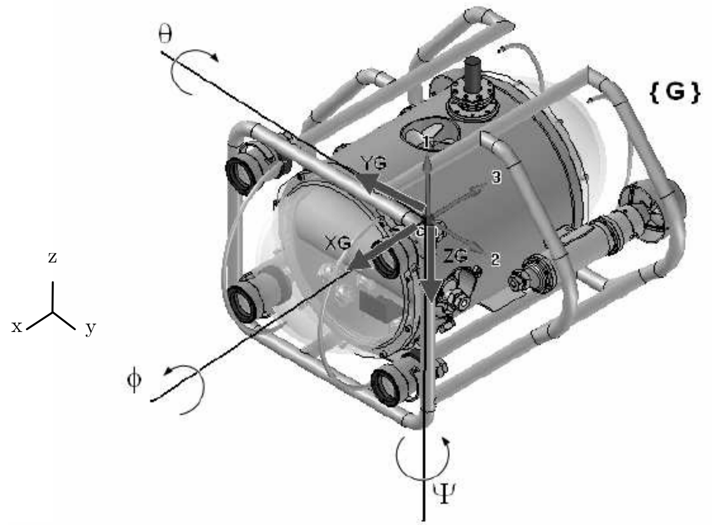
OBSERVATION

MINI ROV

Principal parts of ROV



International notation for the position, orientation, speed and forces for a ROV

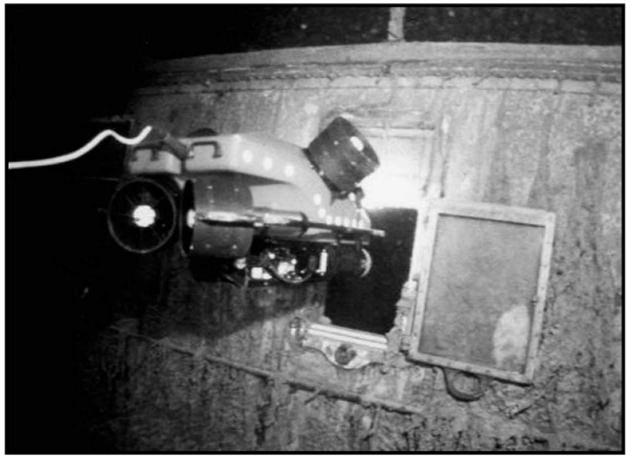


DOF	Motion definition	positions and Euler angles	linear and angular velocity (V)	forces and moments [F;T]
1	SURGE (motion in the x-direction)	X	u	X
2	SWAY (motion in the y-direction)	Y	v	Y
3	HEAVE (motion in the z-direction)	Z	w	Z
4	ROLL (rotation on x-axis)	$\varnothing$	p	K
5	PITCH (rotation on y-axis)	θ	q	M
6	YAW (rotation on z-axis)	ψ	r	N

Universidad Pontificia Bolivariana

History

One of the biggest reaches for the ROV is the exploration of the Titanic in 1986, during which it was attached to Alvin by a 91m fiber optic cable.



Jason Jr.

Alvin

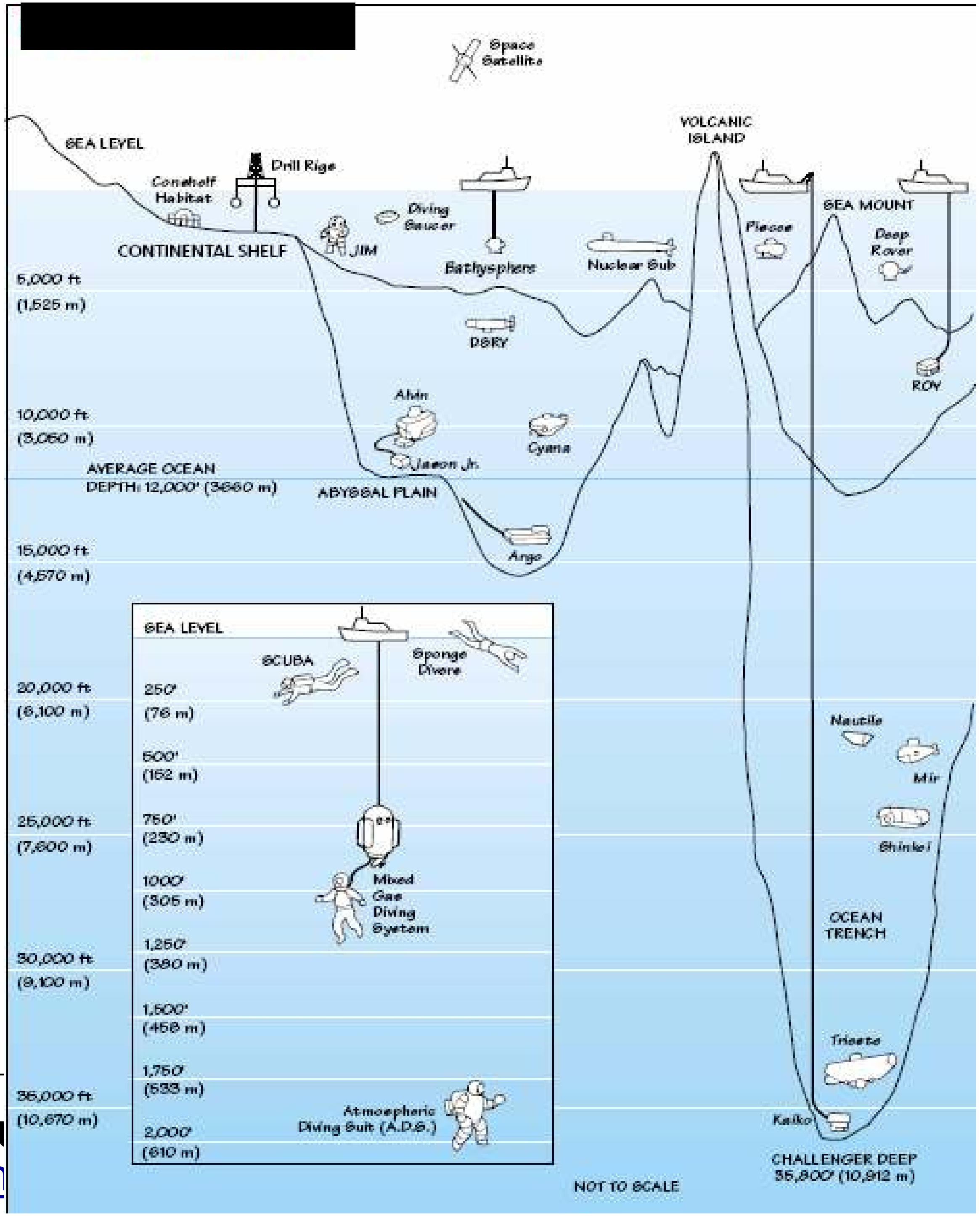
Limitations of the diving

- There are two diving types: scuba and the technician.
- The scuba diving can reach up to 40m, the technician up to 120m of depth.
- The scuba diving not have communications with the surface; the technician has an umbilical cord for the communication.

SCUBA

TECHNICIAN

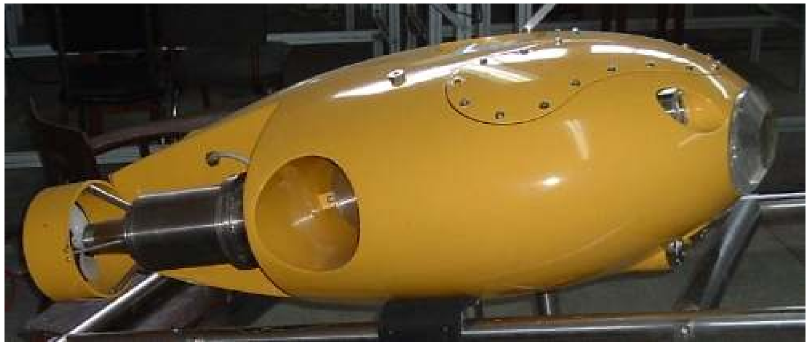
Reached depths



AU
h

PREVIOUS EXPERIENCIES

- VISOR I: developed in 1994, for inspection tasks at a design depth of 40 meters depth.
- VISOR II: developed in 1998 as dual vehicle: autonomous and remotely operated. The design depth was 100 meters.



Design Constraints

- Working depth: a maximum operational depth is about 18.3 m. but a higher depth is chosen to avoid limitations to the operational capabilities of the vehicle. In this way, a 100 m maximum value is selected which is equivalent to a hydrostatic pressure of 1.00 MPa (145.5 psi).

Port	Maximum depth (m)
Barranquilla	12.0
Buenaventura	13.7
Cartagena	13.7
Santa Marta	18.3

- Design depth: The design depth establishes a security margin for the collapse resistance of the hulls and other structural elements. In this case a depth of 165 m is chosen, which is equivalent to a hydrostatic pressure of 1.66 MPa (240 psi).

- Operational speed: The operational speed depends on the highest port current speed. accordingly to port’s conditions, the maximum operational speed is defined as 1.5 m/s.

Plymouth
Basse-Terre
Roseau
Castries
Kingstown
Saint George'
Managua
Oranjestad
Willemstad
Santa Marta
Barranquilla
Maracaibo
Caracas
Valencia
Isla Coche
Cartagena
San José
Costa Rica
Ciudad de Panamá
Venezuela
Isla Leones
Medellín
Bogotá
Buenaventura
Colombia
Cali
Isla Santa Rosa
Quito
Ecuador
Image NASA

Universidad Pontificia Bolivariana

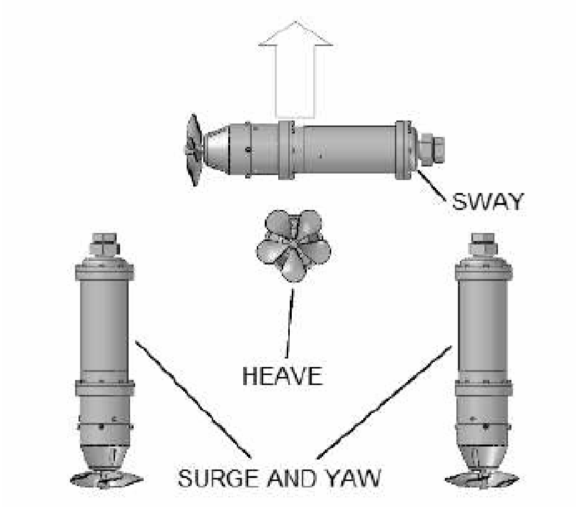
Subsystems of the vehicle

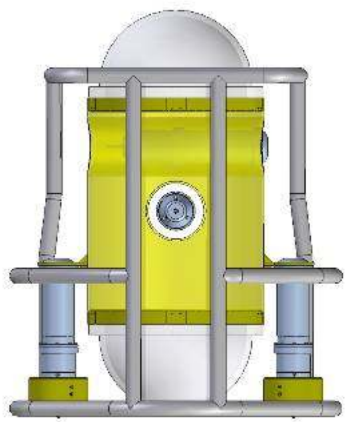
The vehicle is divided into four subsystems:

- Structure
- Propulsion system
- Electronic devices
- Illumination system

Propulsion system

A four-screwed-propeller-thruster system is used. Two of them are used to provide surge displacement and yaw rotation. One thruster is used to provide heave displacement, and the last one is used to provide sway displacement.

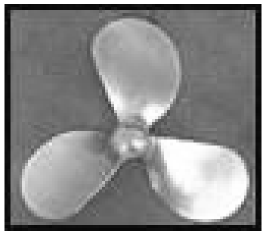


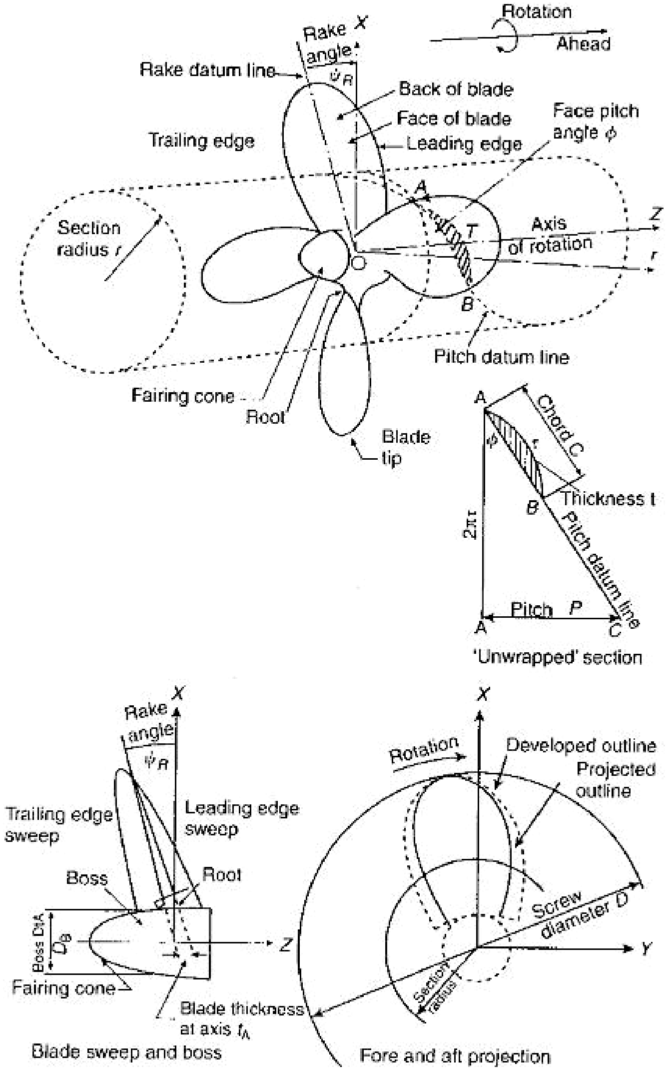


Thrust forces and Propeller

•The propeller transforms most part of the input power into thrust force.

•The thrust force produced by the propeller and transfered to the water, varies due to inefficiencies of the propeller, the motor-reductor set, the drive shaft assembly and the sealing systems.





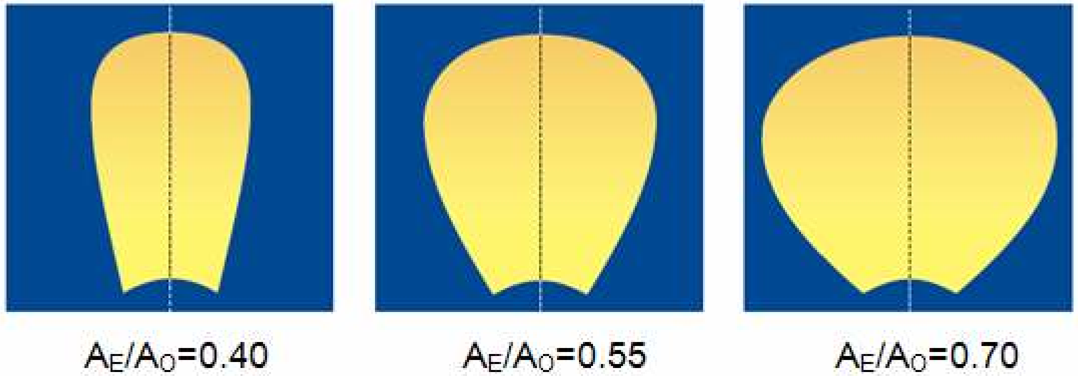
Parameters for selection

The parameters for selection of propellers are:

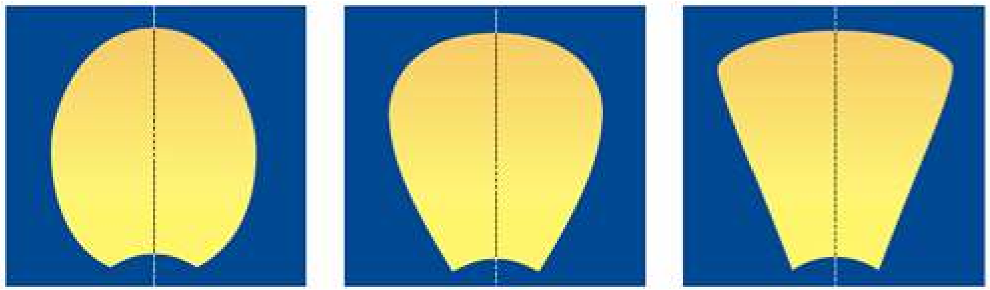
- Identification *(bronze 3- bladed 20 x 10 RH)*
- Material *(bronze, steel, stainless steel, aluminum and plastic)*
- Rotation direction
- Diameter
- Number of blades
- RPM
- Pitch
- Slip
- Area of action

Parameters for selection(2)

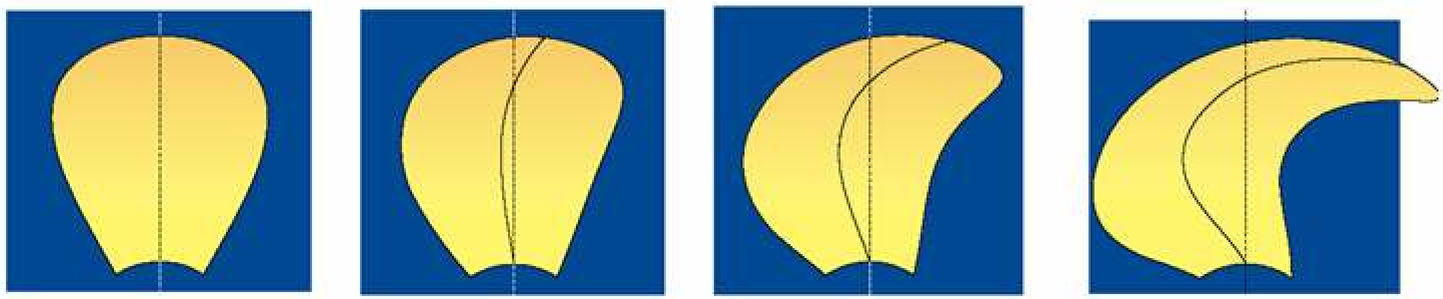
DEVELOPMENT AREA



SHAPES OF THE BLADE



SKEW ANGLE



Simplifications

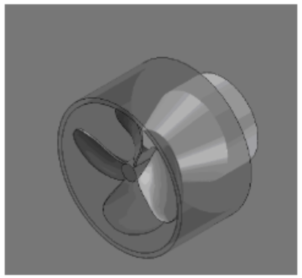
- Flow incompressible and Newtonian.
- K-E turbulent model.
- The axis of the propeller rotates at angular speed constant.
- The advanced speed of ROV is constant.
- Blade surface with a relative roughness of zero (ideally smooth).
- Average blade thickness was used.

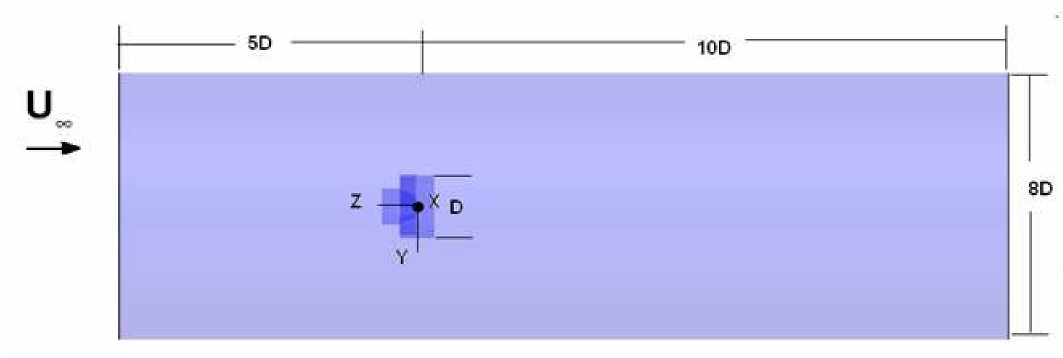
Solution strategy

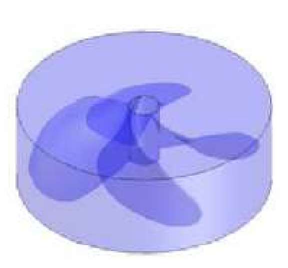
To solve the problem two domains were defined:

•A stationary domain that covers the open flow and propeller's knort nozzle and motor zone.

• A domain that covers the zone were the propeller rotates.





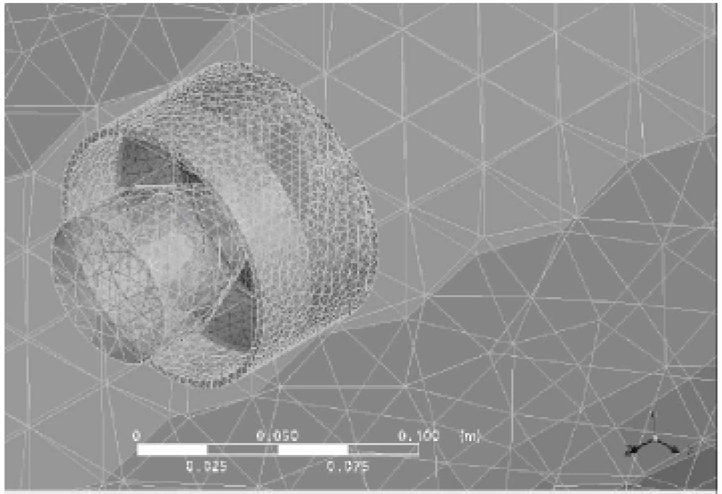


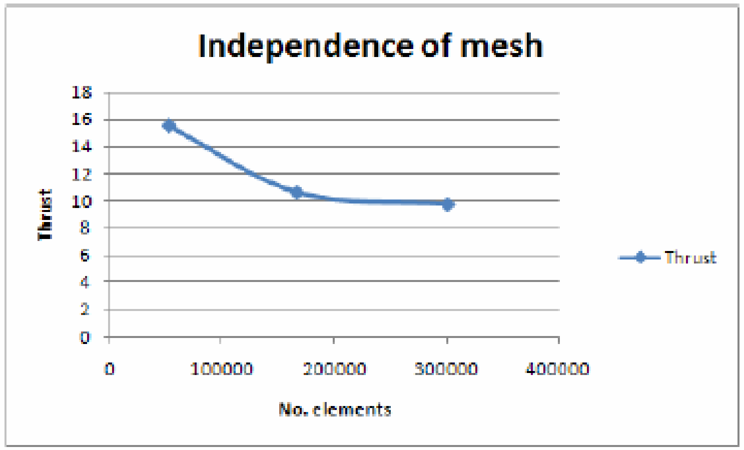
Mesh

- The domains were meshed with unstructured meshes using tetrahedral elements.

- The propeller's mesh was more refined to observe in detail flow's behavior in the root, surface and the edge of the blade. The independence of mesh was considered when refined, it looking for a balance among the times of compute and the decrease of the residual error RMS.

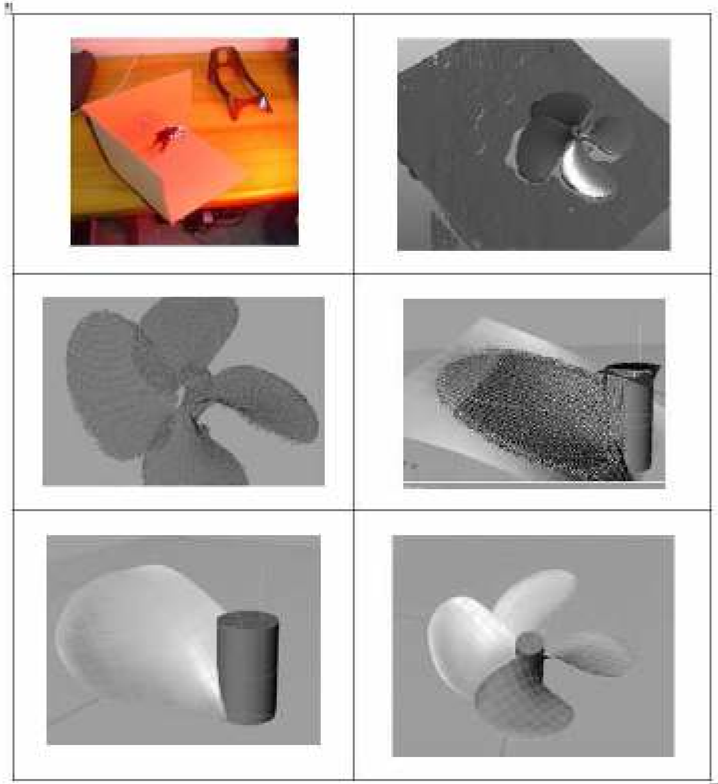
- Some simplifications were made in the geometry of the model: elimination of holes, rounds and fillets, also an average blade thickness was used.



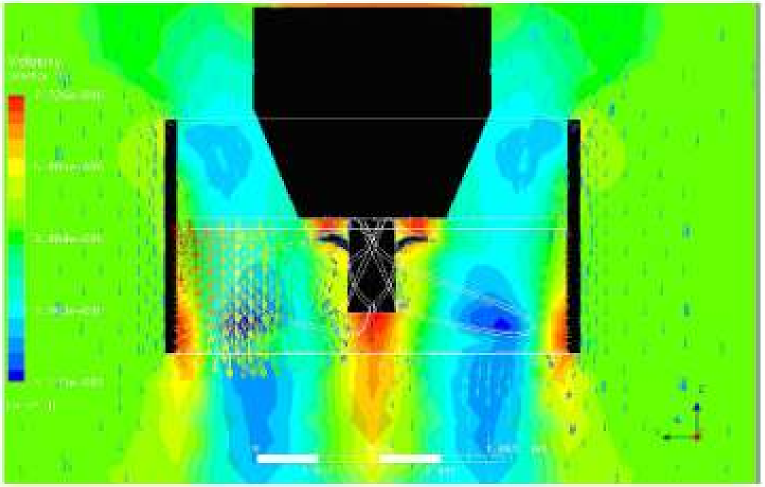


Inverse engineering process

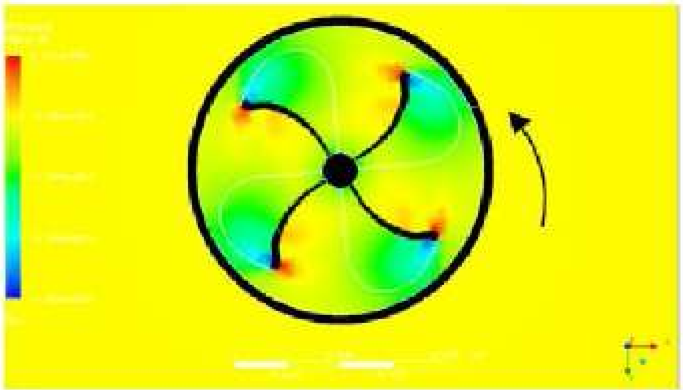
The propeller's CAD model was generated through an inverse engineering process, where a series of refinements were made from the cloud point to the generation of the surfaces and the later



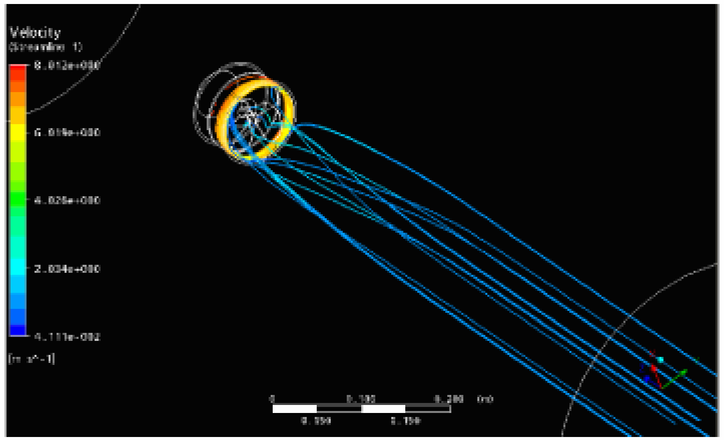
Results



Velocity z profile



Pressure distribution



Pathlines

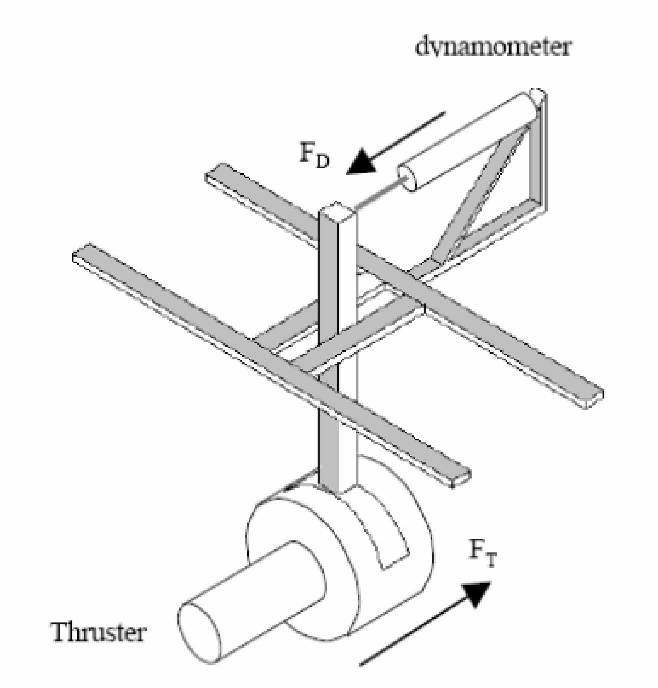
Results (2)

Angular speed(rad/s)	Thrust(N)
80	1.20233
100	2.73062
120	4.71011
140	7.12013
160	10.4934
180	13.0826

Variable	Value
Thrust	10.5813 N
Torque	0.162974 Nm
Power	27.3796 W
J	0.420696
K_Q (Torque)	0.0400913
K_T (Thrust)	0.231406

Results of the monitored variables (Steady state)

Recommend Validation



Drag forces

- The movement of a fluid around a submerged body, it can affect significant the dynamics of the vehicle, due to the fluid can transfer momentum to the body and it changes its direction.

- A fluid moves when there is a difference of pressures between an zone and another.

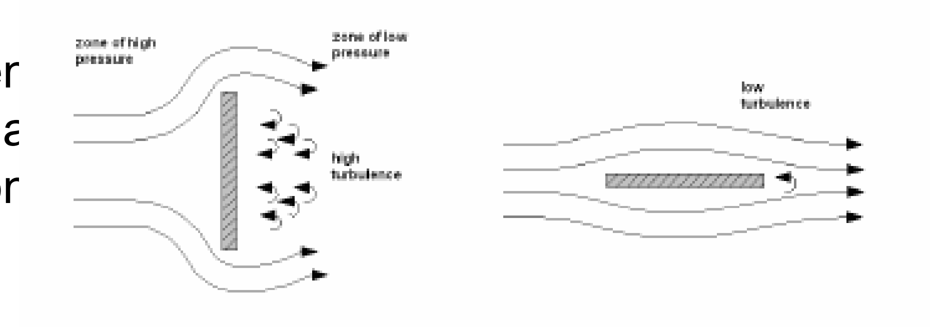
- The reduction of the drag of a submergible means that requires less thrust to move and therefore save consumption energy .

- Two properties to consider in the transfer the momentum and acting significantly in the boundary between the fluid and the body are the viscosity and the pressure.

Drag forces(2)

•There are two types of drag forces: pressure drag and viscous drag.

•The pressure drag is generated wher the fluid collides with a front side of a body, that trying to change the directior of its movement.



The viscous drag is small

The pressure drag is small

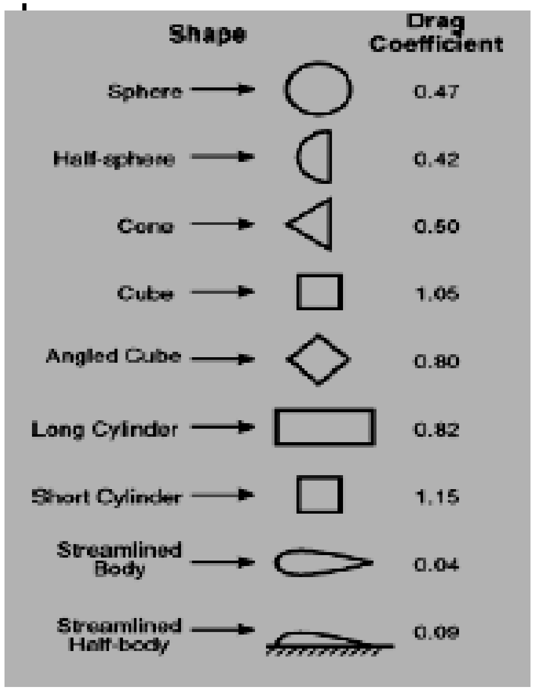
•The viscous drag is given due to the push of some molecules with others of the fluid and the submerged bodies.(skin friction).

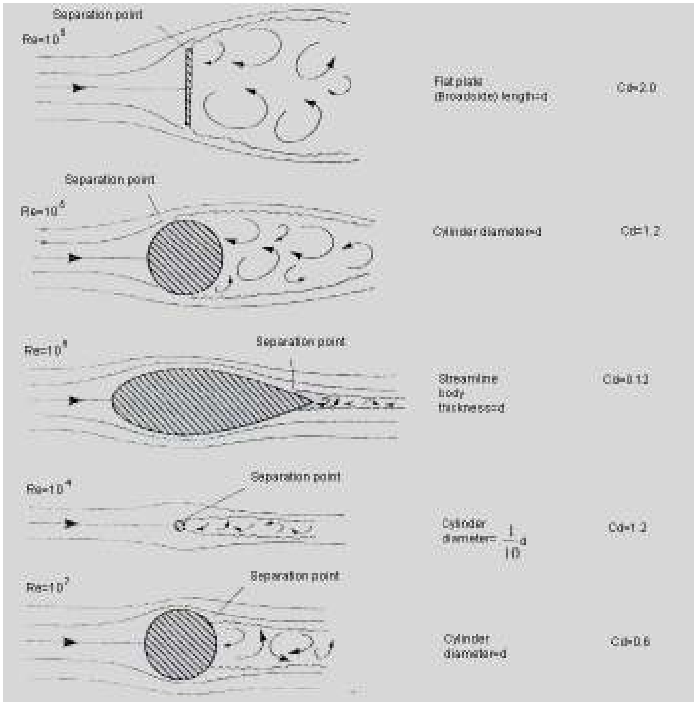
•A classification of bodies depending of the drag is: blunt body where the drag is mainly by pressure and streamlined body where the drag is mainly by friction.

Reduction of the drag

•The drag coefficient (Cd) is an adimensional number that relates the speed, the front area of a body, geometry and the density of the fluid.

•Geometries that present values of Cd below 0.75 are considered of low drag; geometries that present values above 1.0 they are considered of high

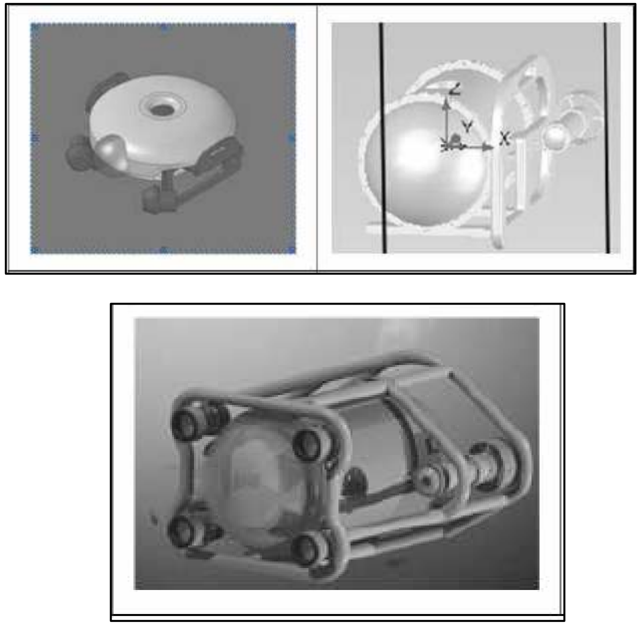




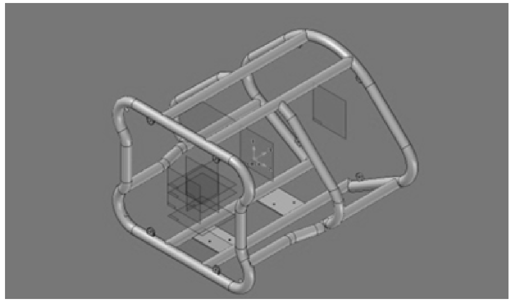
Scope of this study

•Optimize the geometry of the vehicle, reducing its drag at operation conditions.

•Revise the influence in the drag of the protector frame.



CAD Models



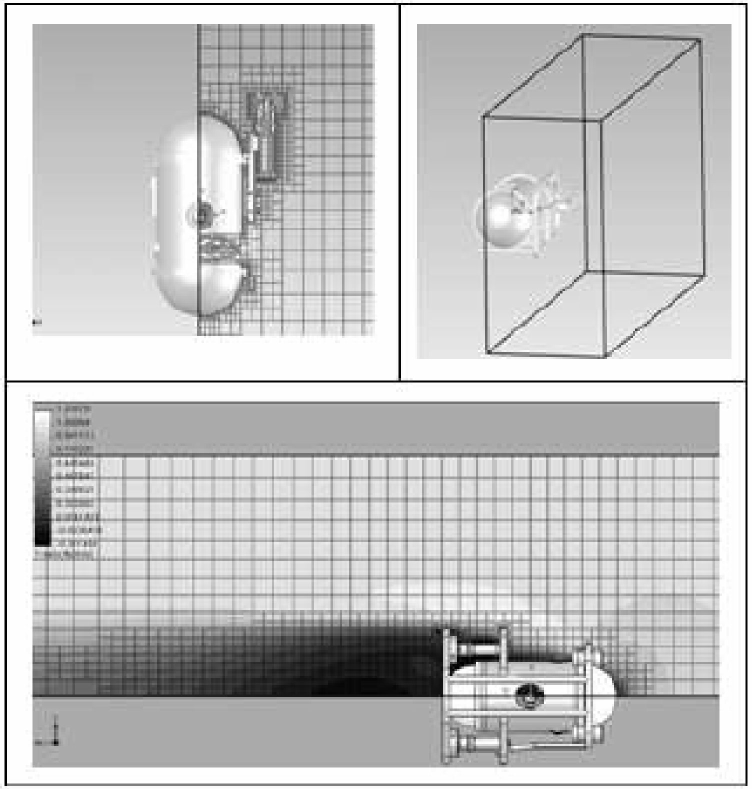
Protector frame

Solution strategy

- In the domain to use the geometric symmetry of the vehicle, reducing the time of calculation.

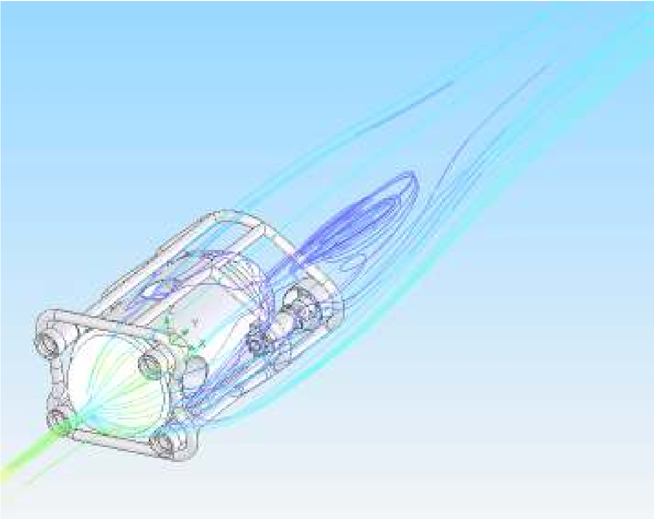
- Several scenarios were analyzed taking into account different flow directions.

- The mesh was refined to see phenomenas of the boundary layer and the wake. The independence of mesh was considered when refined.



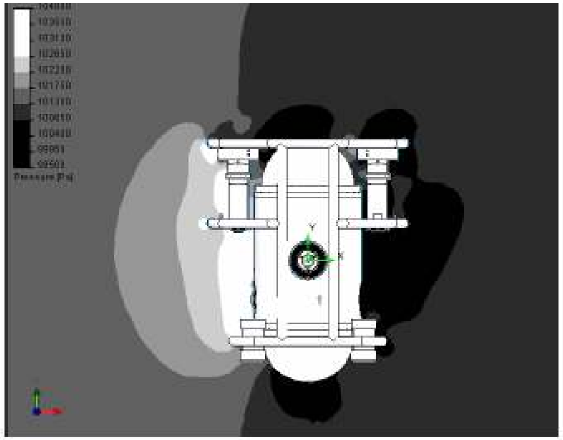
Scenarios and results

Scenario	Speed of flow(m/s)	Direction	Symmetric plane
1	0,5	X	no
2	1	X	no
3	1,5	X	no
4	2	X	no
5	-2	Y	yz
6	-1,5	Y	yz
7	-1	Y	yz
8	-0,5	Y	yz
9	0,5	Y	yz
10	1	Y	yz
11	1,5	Y	yz
12	2	Y	yz
13	-2	Z	yz
14	-1,5	Z	yz
15	-1	Z	yz
16	-0,5	Z	yz
17	0,5	Z	yz
18	1	Z	yz
19	1,5	Z	yz
20	2	Z	yz

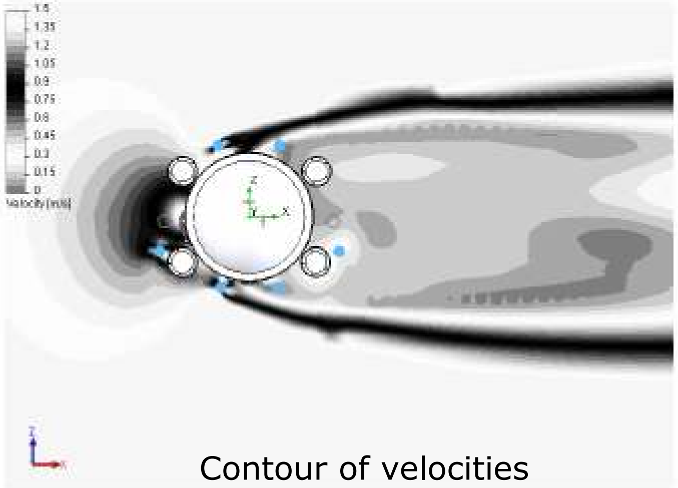


Scenario	Velocity of flow(m/s)	Drag force(N)	Scenario	Velocity of flow(m/s)	Drag force(N)
1	0.5	19.7340	11	1.5	115.9913
2	1.0	80.4129	12	2.0	206.8227
3	1.5	183.5303	13	-2.0	312.0044
4	2.0	325.5736	14	-1.5	182.4368
5	-2.0	201.6333	15	-1.0	-81.3388
6	-1.5	127.1545	16	-0.5	-20.8437
7	-1.0	-49.6851	17	0.5	20.8238
8	-0.5	-13.7174	18	1.0	83.3983
9	0.5	13.0339	19	1.5	186.6005
10	1.0	51.3490	20	2.0	328.5758

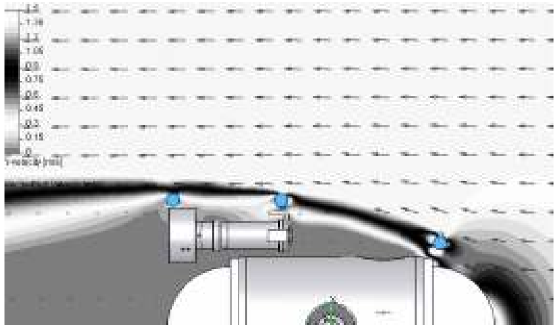
Results(2)



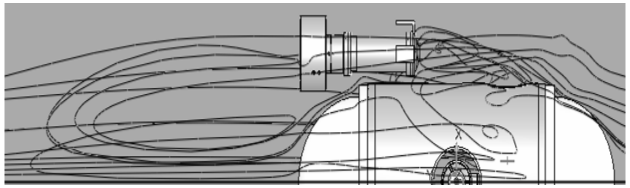
Contour of pressures
(sway movement)



Contour of velocities
(sway movement)

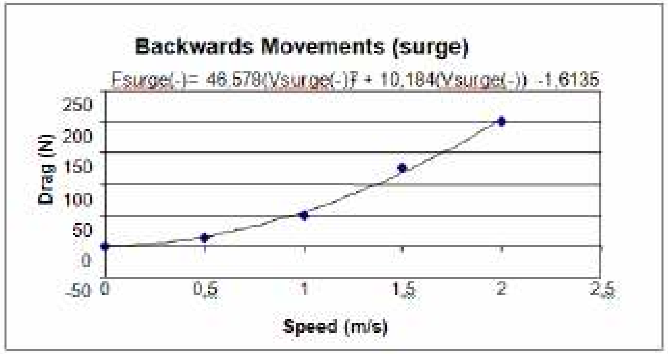


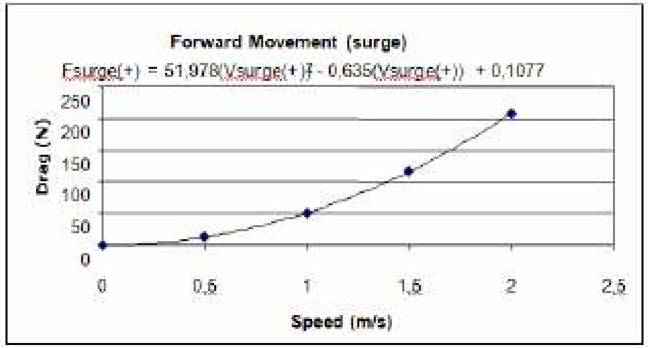
Contour of velocities
(surge movement)

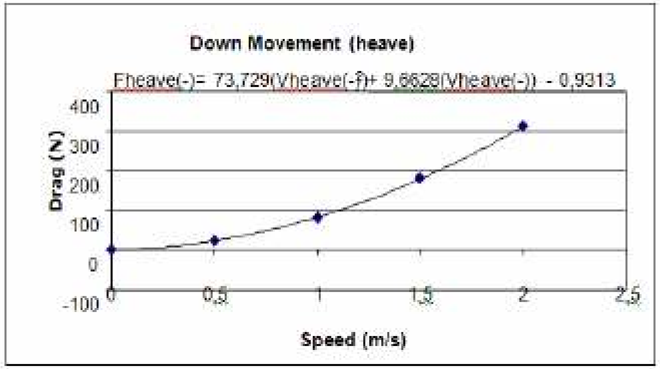


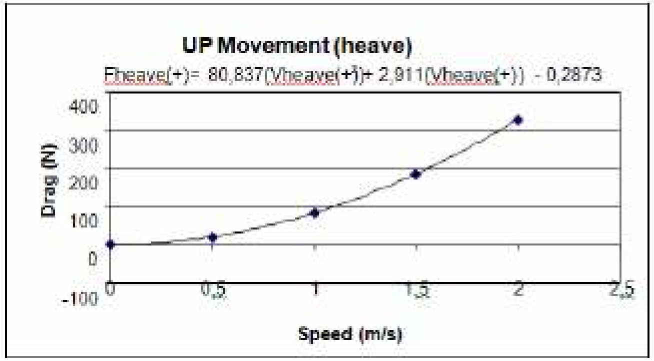
Pathlines
(surge movement)

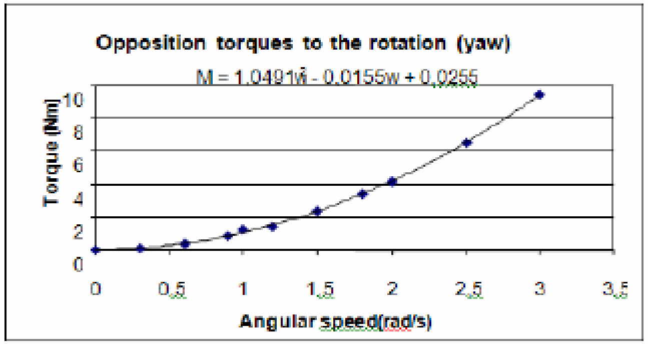
Results(3)

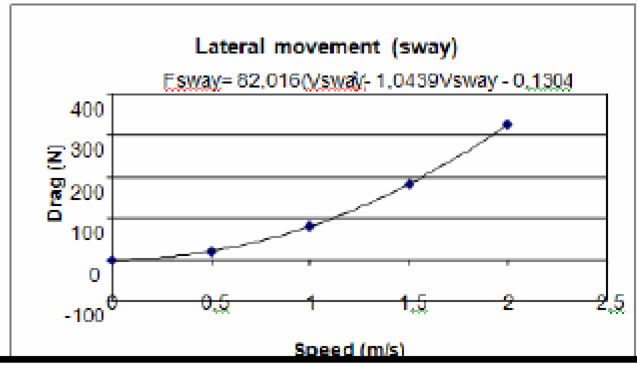

Backwards Movements (surge)
Fsurge(-)= 46,578(Vsurge(-))² + 10,184(Vsurge(-)) -1,6135
Drag (N)
Speed (m/s)


Forward Movement (surge)
Fsurge(+) = 51,978(Vsurge(+))² - 0,635(Vsurge(+)) + 0,1077
Drag (N)
Speed (m/s)

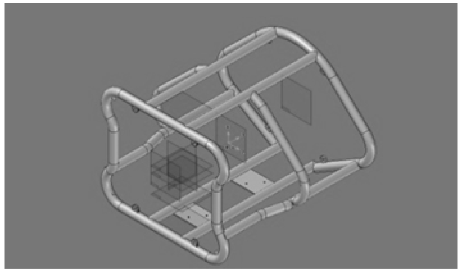

Down Movement (heave)
Fheave(-)= 73,729(Vheave(-))²+ 9,6628(Vheave(-)) - 0,9313
Drag (N)
Speed (m/s)


UP Movement (heave)
Fheave(+)= 80,837(Vheave(+))²+ 2,911(Vheave(+)) - 0,2873
Drag (N)
Speed (m/s)


Opposition torques to the rotation (yaw)
M = 1,0491w² - 0,0155w + 0,0255
Torque (Nm)
Angular speed(rad/s)


Lateral movement (sway)
Fsway= 82,016(Vsway)²- 1,0439Vsway - 0,1304
Drag (N)
Speed (m/s)

Results(4)

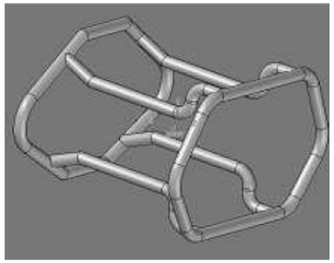


Protector frame 1

Direction	Force [N] Without frame	Force [N] With frame
Surge(+)	71.860	115.991
Sway(+)	115.517	183.530
Heave(+)	167.680	186.600

Power [w] Without frame	Power [w] With frame	Reduction of power [percent]
107.790	173.986	38.047
173.276	275.295	37.057
251.521	279.900	10.139

Results (5)



Protector frame 2

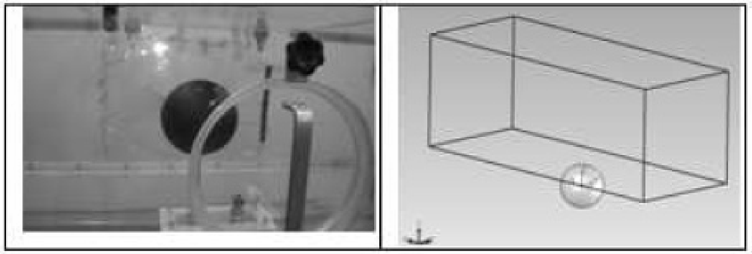
Direction	Force (N)		Direction Torque	Torque (Nm)		Potencia (W)		Reduction of power (%)
	Frame 1	Frame 2		Frame 1	Frame 2	Frame 1	Frame 2	
Surge (+)	115,991	91,813	x	-1,538	-0,325	173,986	137,720	20,84
Sway (+)	183,530	116,235	z	-6,930	-3,088	275,295	174,353	36,66
Heave (+)	186,600	170,081	x	7,688	7,597	279,900	255,122	8,85

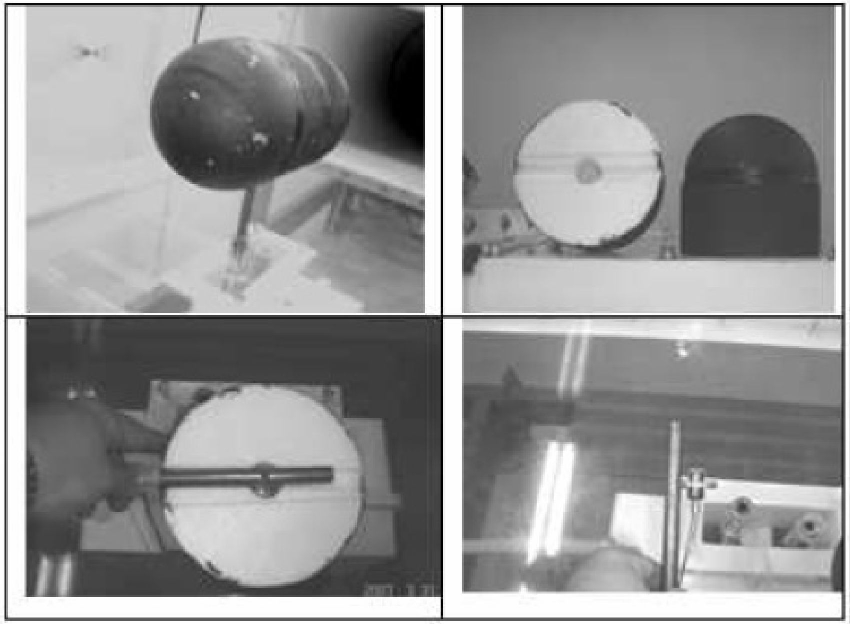
Experimental validation

- Experimental validation in the wind tunnel.

- Analysis of two shapes: sphere of fixed diameter and a cylinder with the ends with semi-spheres.

- Apply the theory of similitude: geometric, kinematic and dynamic.





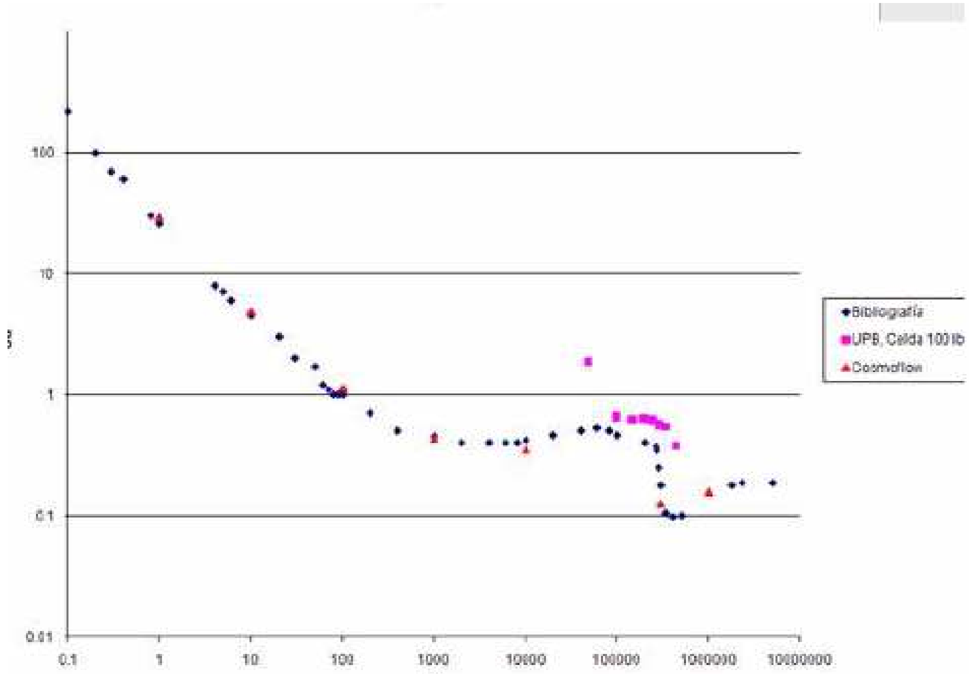
Calibration of the load cell

•Mesurements of drag forces with a Load Cell (nominal capacity of 25 lbf).

•The calibration was made by the laboratory of metrologic of EAFIT under the norm NTC ISO 7500-1 (Verification of machines of test tension/compression: calibration of the system of measurements of force).

Results of validation

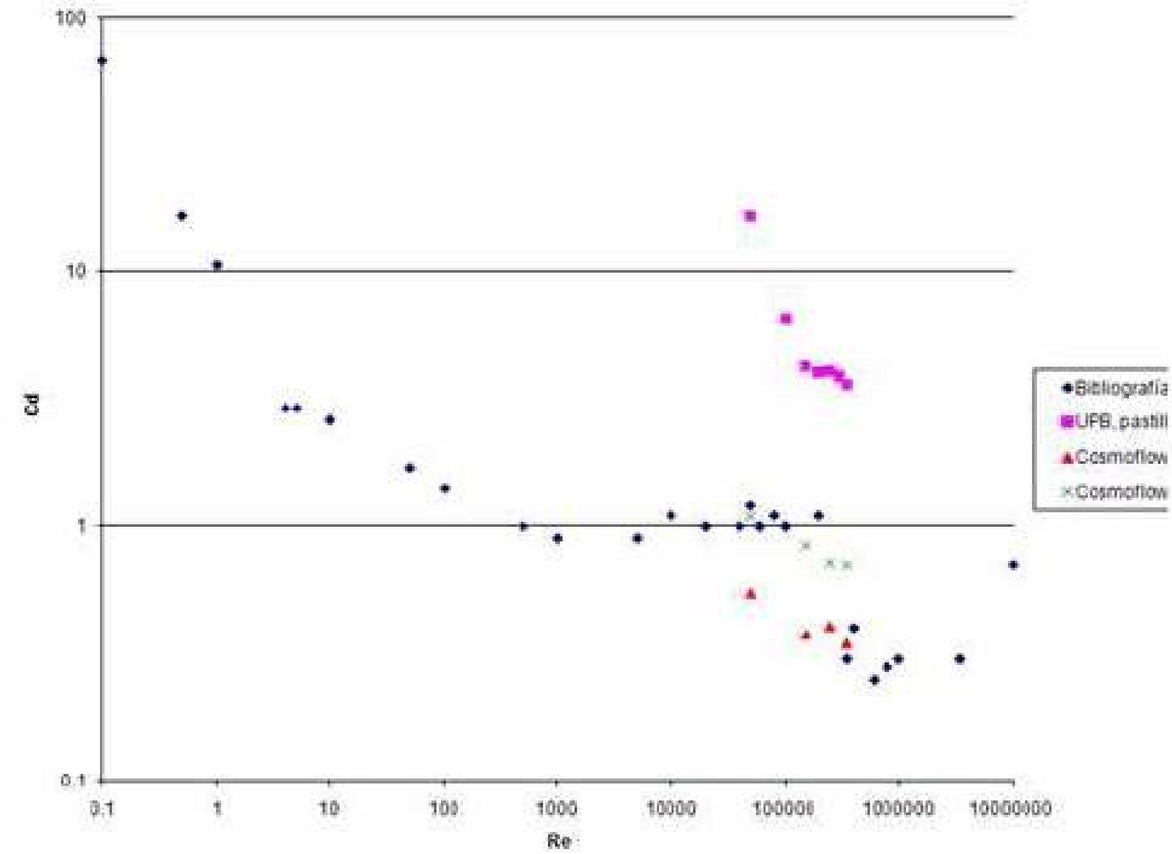
Sphere



Reynolds	Cd		Error [percent]
	CFD tools	Bibliographical registrations	
1.00140	29.5342	30.00	1.55
10.0136	4.8676	4.20	15.90
100.1362	1.1364	1.10	3.31
1001.3624	0.4360	0.40	9.00
10013.6240	0.3529	0.38	7.14
300408.7193	0.1251	0.14	10.61
1001362.3978	0.1573	0.14	12.36

Results of validation (2)

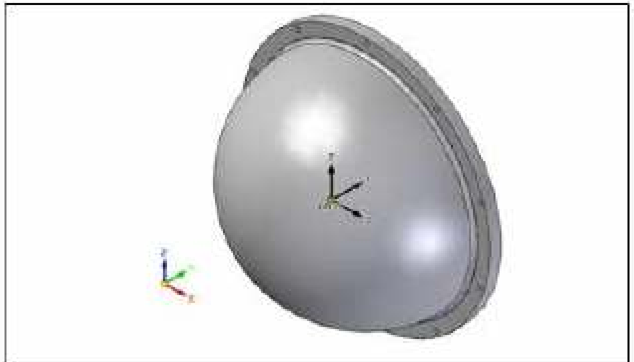
Transversal
cylinders



Structural analysis of dome

•The dome is one of the main parts of the ROV, since it is the place where the camera is located for the capture of video, one of the main tasks of the vehicle.

•The scope of this study is analyze the behavior structural of dome and the stress that it will be subjected to operation conditions, with the objective of calculating the optimal tickness.



Structure

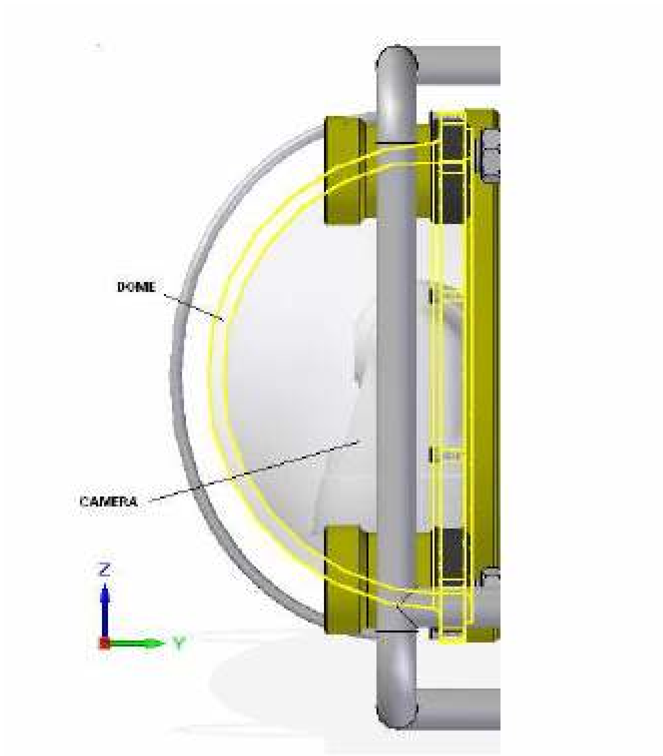
The structure of a submergible vehicle must resist three types of stress:

•Impact forces when it is built, stored, transported, repaired, loaded, among others.

•Hydrodynamic forces when the vehicle moves through the water.

•The hydrostatic pressure..

It exists several failure criteria like yielding, instability, fatigue, fracture, creep and corrosion.



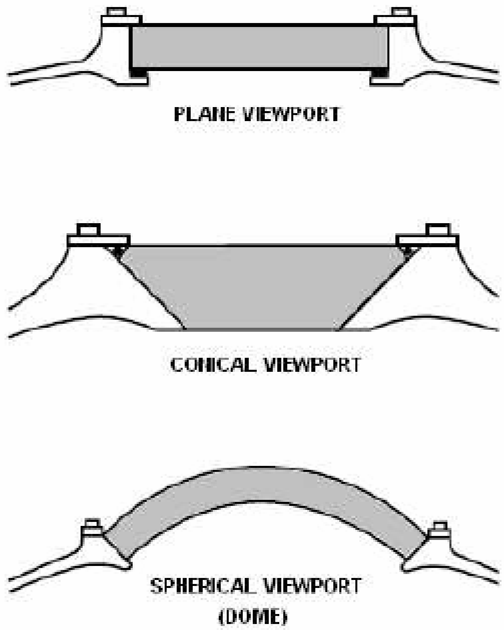
Structure (2)

In the design of the structure of the hull of a submergible should be considered these aspects:

• Use materials that have high resistance and be light, looking for to minimize the mass of the vehicle.

• Minimize the superficial area.

• Use shapes of high resistance to the pressure.



Types of viewports

Structure (3)

- The selection of the material is one of the important stages in the design of the hull .

- Obtain the biggest strength to the pressure, with the smallest weight of the possible structure.

- The common materials of manufacturing of visors are not metallic like glasses, acrylic, plastics of reinforced glass and fiber of reinforced plastic.

- The membrane theory is a starting point to calculate the normal forces to the hull and to obtain an approximate wall thickness.

- It is considered thin wall when the thickness and radio ratio (t/R) is smaller than 0.05 and of thick wall when the ratio is between 0.05 and 1.0.

Suppositions

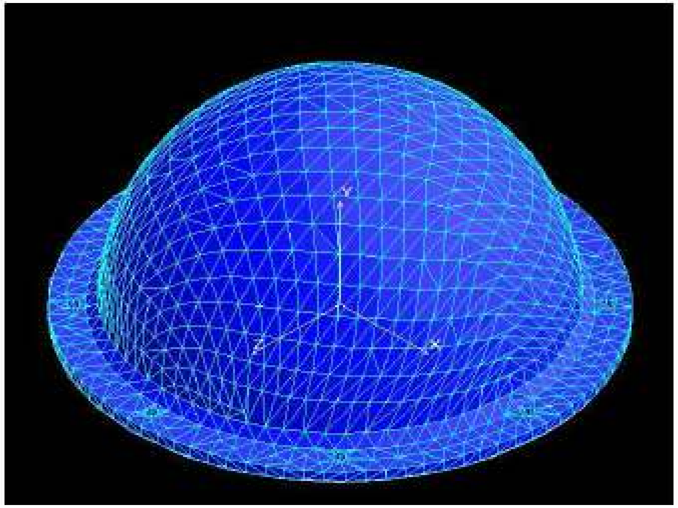
- The effect of the dynamic pressure that the flow of water produce, it is insignificant with regard to the value of the hydrostatic pressure.
- As initial approach it considered the spherical dome like a recipient of thin wall.
- The conditions of the scenario to study correspond to a depth of 100 m, a density of the salted water of 1024 kg/m^3 and an approximate temperature of 4 $^\circ C$.
- The material of the dome is homogeneous.
- The dome will be subjected to small deformations.

Material of dome

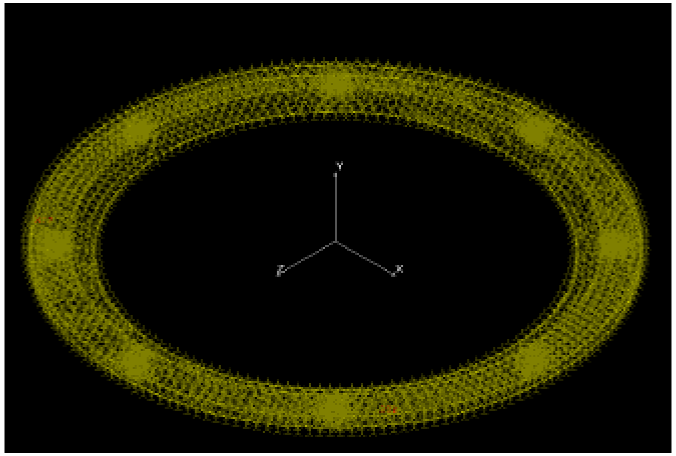
Some properties considered of acrylic (data of www.matweb.com):

- Density(g/cc) 1.15-1.19
- Ultimate tensile strength(MPa) 47-79
- Tensile yield strength(MPa) 55-85
- Tensile modulus(GPa) 2.2-3.8
- Shear modulus(GPa) 1.4

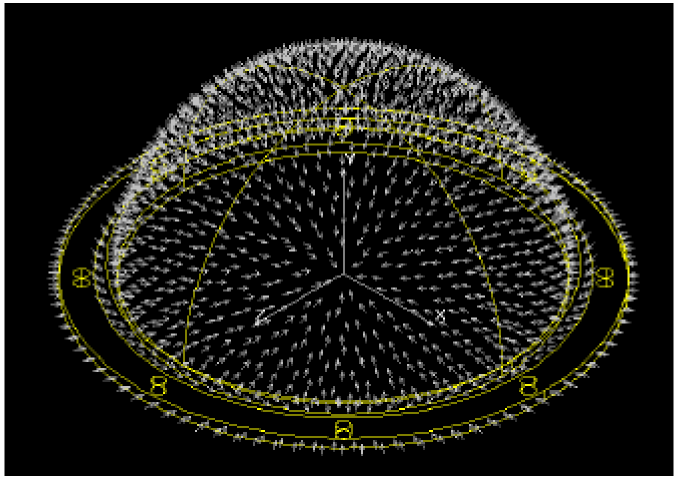
Boundary conditions



Mesh



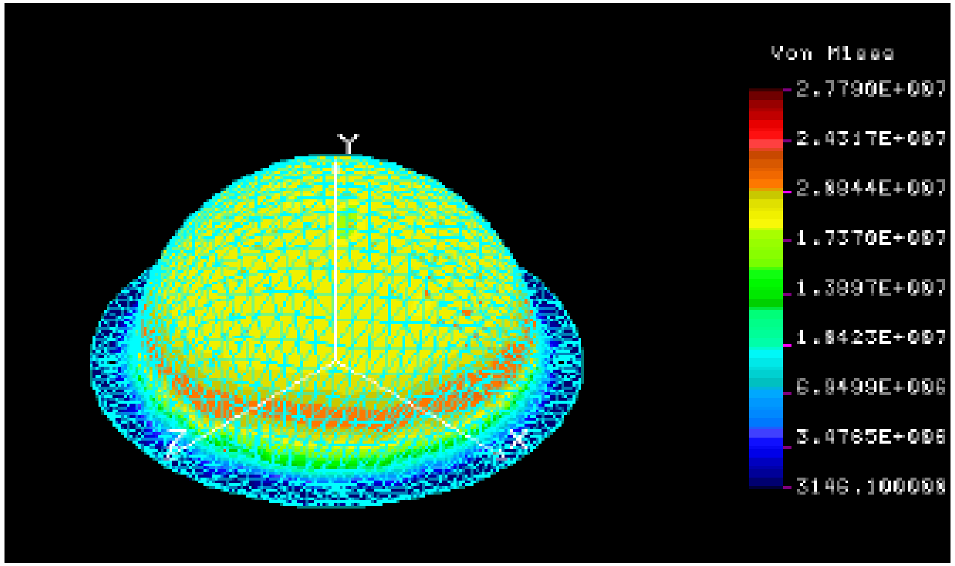
Fixed zones of the domain



Zone subjected to the pressure at 1MPa

Results

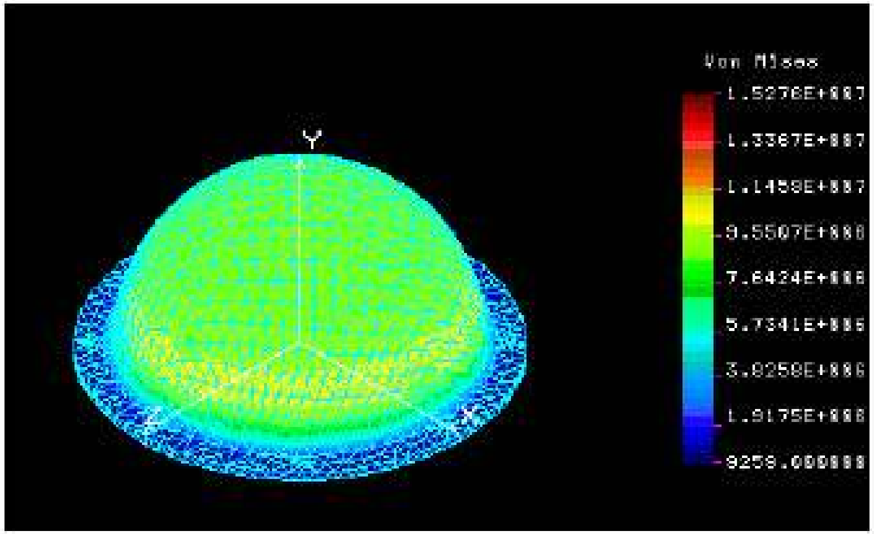
- The maximum stress was 27.8MPa
- Factor of security of approximately 2



Von Mises (Pa)
(thickness 2.5 mm)

Results (2)

- The maximum stress was 15.27MPa
- Factor of security of approximately 4



Von Mises (Pa)
(thickness 5mm)

Recommend Validation

To validate the results obtained with the software of finite elements, it is necessary to make a structural test of dome of the ROV after manufactured, to simulate operation conditions and it can to evaluate the thickness of wall obtained by FEA, by the membrane theory and by vessels of pressure.

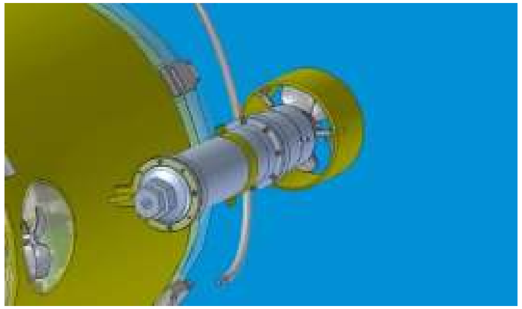
This test must make to different pressures and different intervals of time, according to parameters of the norm applied in the revision of commercial pipes. The objective is to make a visual inspection of the dome for the detection of any anomaly like fissures, bumps, among others.

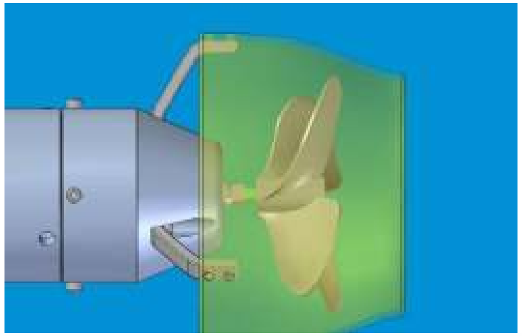
Hydrostatic bomb or of positive displacement

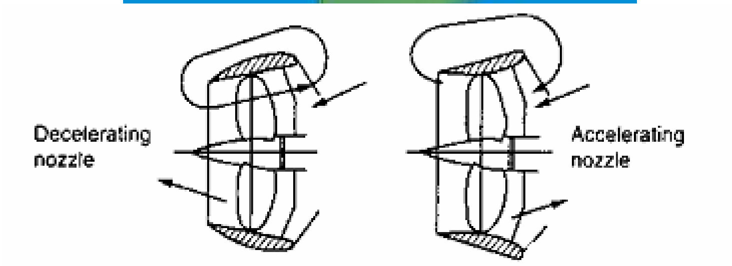
Other products

Knort nozzle:

They are specially used in ROV where are required low speeds and high thrust. It serves like protection of the propeller against a possible impact.







Other products(2)

Program of Blade Theory:

It is possible as starting point, to calculate values of thrust, torque and power for any commercial propeller, based on geometric data like the pitch and the diameter and operation data like the rpm and the advance speed.

```
%programa parametros propela blade theory
clc

%datos de entrada
v=1; %velocidad de avance [m/s]
Dp=0.17;  %diametro propela visor 2 [m]
w=1000*2*pi/60;  %[rad/s]
k=2;    %numero blades
n=3;  %numero secciones
densidad=1024 % densidad agua mar[kg/m^3]

r=[0.030;0.05;0.08]; %radios de las secciones
si=r./(Dp/2);   %radio adimensional
Cb=[0.043;0.059;0.028];    %longitud cuerda[m]
beta=[31;20;12];     %angulo en grados
beta1=beta.*pi/180;
landa=tan(beta1).*pi.*si.*Dp;    %pasos a los radios especificados
J=(2*pi*v)/(w*0.17);     %relacion de avance
Finf=atan(J/(pi.*si));
```

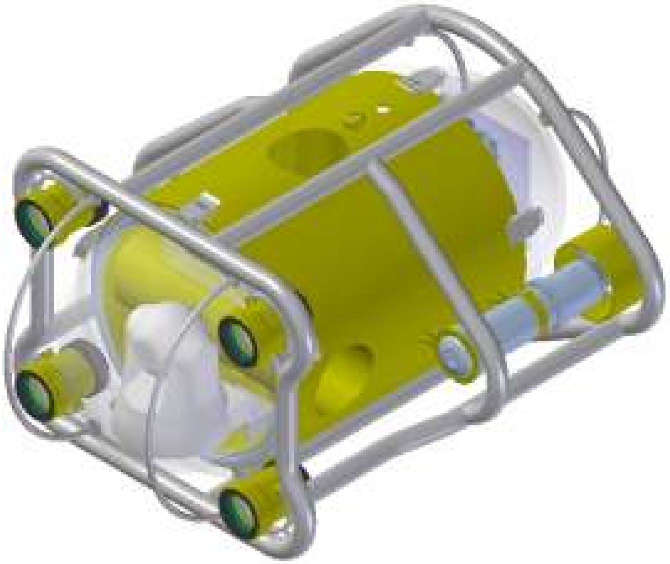
Conclusions

- The results of this study were feedback in the process of design of the vehicle, to predict their behavior before being manufactured the first prototype.

- The detailed design was performed through structural and operational calculations based on analytical and computational mechanics of materials, computational fluid dynamics and classical rigid body mechanics. An appropriate design will guarantee component reliability related to mechanical resistance and functionality.

- Allowed generating a production of knowledge for the investigation of the national universities regarding this topic, when beginning to make an appropriation of foreign technology to cover the local necessities as scientific as industrial.

Design Integration



Conclusions(2)

- For the validation of the computational results, it is necessary to apply experimental tests that allowed to know quantitative values and qualitative effects for taking decisions in the general design of the vehicle.

- The appropriate use of computational tools improve the study of phenomenas for reducing costs and extend the range of analysis conditions, that which impacts in the investigation.

Universidad Pontificia Bolivariana

Simulation of the thrust forces of a ROV

THANKS!

Raúl Valencia