150 YEARS LATER: FROM THE ICTÍNEO (1859) TO ICTINEU3, A MODERN MANNED SUBMERSIBLE FOR SCIENTIFIC WORKS

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Abstract. In 1859 Narcís Monturiol launched his first submarine in Barcelona. The *Ictíneo* (fish-boat in Greek) was an olive wood-copper ellipsoid enclosed in an outer hull. The submersible (7m long, 10 tons displacement) could fit up to six people and it was designed for 50m depth. In 1864 a second Ictíneo was built: 17m long, 72 tons displacement, it employed an anaerobic engine able to produce steam for propulsion and breathable oxygen. In both ships he introduced new and very cuttingedge solutions for that time and with the treatise he wrote, it can be said that he established the bases for modern underwater navigation. After 150 years the firm *Ictineu Submarins* is developing a modern scientific submersible. It will dive down to 1200m and host a crew of up to three people. It will be called *Ictineu3*, paying tribute to its old ancestor.

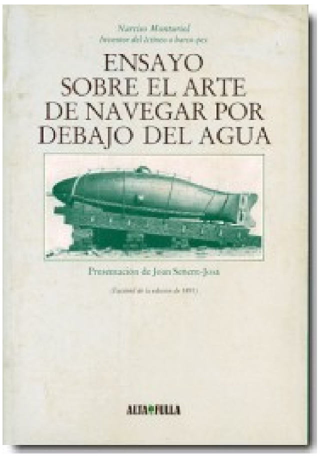
Key words: artificial atmosphere, chemical engine, composites, double hull, FEM, Ictíneo, Monturiol, propulsion, sensor platform, sphere, steel, viewport.

NARCÍS MONTURIOL

Narcís Monturiol (Figueres, 1819–Barcelona, 1885) was an inventor who deeply contributed to the underwater navigation development, building two submarines. Almost forgotten by history, he achieved great results 150 years ago (XIX century), when there was no internet, no instant communication and the technology available was far poorer than nowadays. The only information he accessed were a few articles by the French Montgéry about underwater navigation and the Fulton's analysis of his Nautilus. Monturiol was neither the first to have the idea nor the first to build an underwater craft. Because of lack of information, he could not evolve from other inventions, only taking advantage of some ideas. He almost had to start from scratch developing new solutions to build his submarines. From this point of view we can say that he is the submarine inventor, in the modern sense we intend today. During his life Monturiol wrote the first treatise of underwater navigation, leaving us a written document.

THE ESSAY

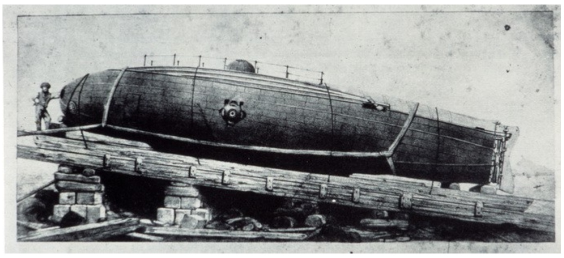
In 1891, six years after his death, the book "Essay on the Art of Underwater Navigation" was eventually published. The inventor's magnum opus was the starting point of many other inventors: Isaac Peral admitted it publicly (*"I would have never been able to build my submersible without Monturiol's inventions")*; in 1905 Germany used this essay as a technical document to create its underwater fleet, so fundamental during the two World Wars, and named "ictineo atmosphere" the breathable air solution for the human chamber. In general it is not always accepted but it is from this book that operative submarine construction really starts, with examples like Gymnote of Gustave Zédé (1888) or John Holland's submarines (1898), all for military applications.



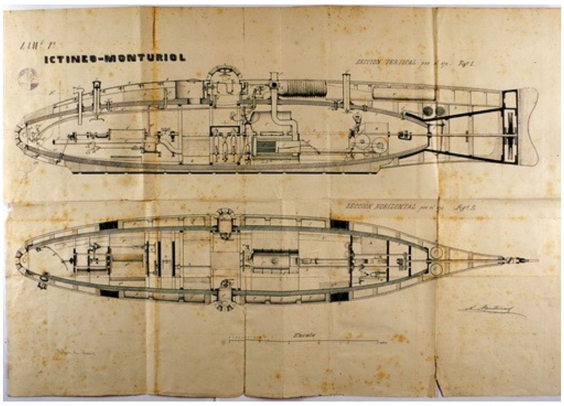
MONTURIOL'S CONTRIBUTIONS

From a technical point of view, Monturiol's innovations are vital for underwater navigation. He was the first to determine how an underwater craft has to behave, the first working in team, with different technicians in different fields, doing many trials in order to know the marine environment, always under the main concern of diving in safety conditions. He was a pioneer in building a double hull vessel, in creating the artificial atmosphere, producing the oxygen and absorbing the carbon dioxide (the same principle still in use today); pioneer from an operational point of view, enabling his craft to move in all directions under wide safety measures, with extensive calculus and emergency features; pioneer for the mechanical propulsion. A twelve years project, with two submarines built, drawings of other submarines realized and an essay for a total amount of money equivalent to M€ 6 without any public funding.

The Ictíneo was the first civil submarine in the world, with no war purpose, for exploration and recovery, with 19 viewports, artificial light to be able to see underwater and manipulators to collect coral and other objects from the sea bottom. It has been the first in diving deeper than 8-10 metres, reaching depths in between 30 and 70 metres (depending from the sources), with continuous operational capability. The first Ictíneo (7m long, 10 tons displacement) was an olive wood-copper ellipsoid enclosed in an outer hull, that could fit up to six people and was designed for 50m depth. It performed 69 dives without any accident. The second one (17m long, 72 tons displacement) performed 19 dives, all of them in safe conditions.



Monturiol dedicated many years for the improvement of the underwater propulsion, always with the same goal of protecting the crew members. At a time when the sea bottom was thought to be a still, desert place, he envisioned that there might be strong currents, forcing a submarine to reach a minimum speed, without which he did not dare to dive for fishing corals. Both with human and with mechanical propulsion he reached a maximum speed of 2 knots underwater. Most of the nowadays submersibles have a cruising speed below 2knots. The second Ictíneo had two steam engines: one for surface navigation, burning coal and able to emit noxious gases; and another for underwater navigation, a chemical engine producing heat for propulsion and breathable oxygen for the crew, with no other toxic gases. Monturiol solved all the technical problems he faced but an economic crisis forced him to cancel the entire project. He had planned to build a third submarine, developed around the new double engine: with an iron hull and a separate and insulated engine room for mechanical propulsion. Monturiol and his solutions were almost 30 years in advance in relation with that time technology. After Monturiol it took 30 years to install again two engines in a submarine. It was not till 65 years that another underwater chemical engine was used (the "Walter" motor in 1932) and almost 100 years until another steam engine was installed, this time a nuclear powered one.
We will have to wait for 89 years before the civil submersible production starts again, that is in 1948, when Auguste Piccard lands with his balloon (FNRS), after establishing the world record in ascension, to dive with the bathyscaph FNRS-2.



The Monturiol's year

The year 2009 will be the 150 anniversary of the first Ictíneo. During 2009 several events will be held to celebrate the first two Ictíneos and their inventor, among which an exhibition on manned submersibles' history at the Museu Marítim of Barcelona.

THE ICTINEU 3 PROJECT

ICTINEU 3 is conceived as a modern submersible which will incorporate innovative materials and advanced manufacturing techniques, efficient and environmental friendly power systems, intelligent management and control systems and the most advanced technologies in security, positioning, navigation, communication, sensing and data logging. It will be a highly versatile tool conceived to be adapted and modified as newer technological solutions become available. A submersible which will play a central role in any scientific work to be imagined under-seas. It will be launched in the first half of 2010.
In order to enhance ICTINEU 3 capabilities, a support ship will be also constructed. It will be a 20m long catamaran designed around the submersible. Its main purpose will be to transport the submersible on surface to the mission site and to assist it in all the necessary aspects during the whole campaign: communications, security, positioning, crew assistance, catering and accommodation. Apart from cabins and kitchen, the ship will host a workshop, a small laboratory and a control cabin with the latest technologies in communication, positioning and control system.

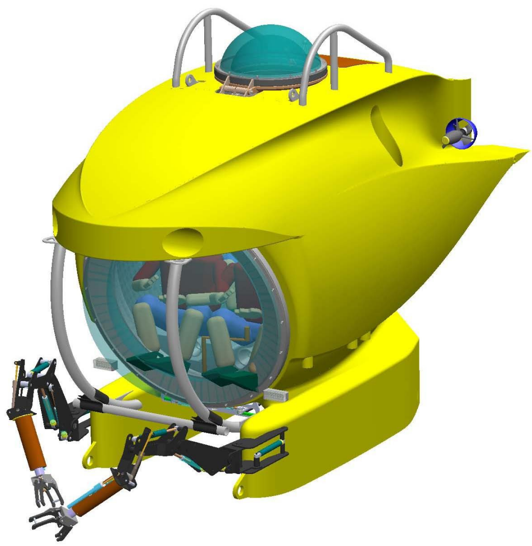
THE ICTINEU 3, DESIGN AND CAPACITIES

The ICTINEU 3 is a small and light weight manned submersible with high capabilities. It is a safe, versatile and customizable tool to perform a wide amount of tasks such as scientific research and underwater intervention. It will dive down to 1200 meters, making it one amongst the ten deepest submersibles in operation at present.

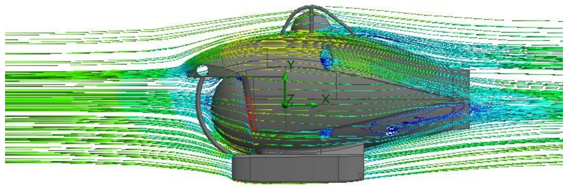
It will be capable of carrying 2 crew members and a passenger, with an operative autonomy of 10 hours, although a typical mission lasts between 3 and 6 hours. It will have reserve oxygen tanks and an emergency autonomy of 12 days.

At the front, a big PMMA viewport (Ø1200 mm) will provide the crew with an exceptionally wide field of view, excellent for high quality photography and video capturing. Nowadays deep subs (below 1000m) do not have wide viewports but small portholes (Ø 200 mm).

The main pressure hull will be composed of a 1700 mm interior diameter sphere linked to a 800 mm diameter sphere on top. The smaller sphere will have the hatch that allows to enter and leave the submersible.



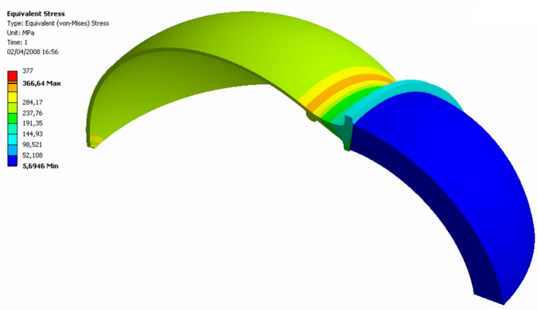
From the operational point of view several milestones have been fixed. The reduced size and a wide front viewport will provide easy and comfortable operation, as well as getting very close to the working area. The hydrodynamic shape has been designed for both optimal navigation and for security reasons (e.g. avoiding stuck into nets). The capability to fully empty the diving tanks at surface will provide 600 mm between the design water line (dwl) and the top hatch. This height together with the external shape design will allow passengers to get in and out the submersible once it is in the water, in good weather conditions. Two internal buoyancy tanks, hosted at the bottom of the pressure hull, will enable trimming and to reach the desired buoyancy saving electrical power for manoeuvring.



The maximum dimensions (4,9x2x3m) will allow to load it in a standard open top container so that it will be possible to transport it on the road with a conventional truck, by train or by ship without requiring special transportation. Given its reduced weight (5 tonnes) it can be lifted with standard cranes on harbours and onboard oceanographic vessels.

One of the main challenge is to integrate the engineering and design stages in order to obtain a small, compact and lightweight submersible with high performances (safety, tools, autonomy). Through analytic and FEM calculations, the aim was to reduce the ratio between the interior volume and the weight, keeping the wall thickness to a minimum, always under the safety conditions imposed by the certification authority. The ideal shape to achieve this result is the sphere. The internal diameter of the pressure hull was chosen in order to get a specific volume, so avoiding the use of high density foam, that would have increased the floatability but also the weight.

The pressure hull steel will be a high grade one, combining high mechanical properties and great corrosion resistance in the marine environment, reducing the maintenance operations and avoiding the use of special protecting coats.



The use of composite materials will allow to reduce the weight, still meeting the certification requirements: all the exterior hull, the water tanks and many supports/reinforcements will be carbon fibre/epoxy resin composites.

Another target is the efficiency: to enhance the performance and reduce the consumption, high efficiency Lithium Ion Polymer batteries will be employed with a total power of 40kW. They will be hosted into the outer pads for safety reasons. These new generation batteries will also determine a weight reduction of around 85% compared to the standard acid lead batteries.

High pressure (700bar=10,000PSI) bottles to store compressed air will be used. The core is an aluminium liner around which carbon fibre is filament winded, allowing to stand internal high pressure and to reduce the weight (57%). These bottles are widely used in the automotive sector (CNG, H_2) but they have never been tested for a manned sub: extensive trials will be performed to guarantee the safety.

The sub will be equipped with DC brushless thrusters: four for propulsion and four for manoeuvring. The power-weight ratio is highly favourable compared to other submersibles. Having more than one propulsion thruster will enable the pilot to steer using the motors only. At cruising speed vertical rudder and planes will help manoeuvring.

As a whole result, the concept design will lead to an internal volume/weight ratio (v/w) of around 0,6, that is a volume inside the hull of 60% of the total sub volume. This ratio is comparable to the one of shallow submersibles (400m). Other submarines for the same depth of Ictineu 3 have a v/w=0,23÷0,46. This will allow the Ictineu 3 to increase the payload: this means higher safety (more drop weight to be released in emergency cases), and more capacity to mount new equipment on board.

The space between the pressure and the external hull will host the sensor platform. It is thought as a highly customizable tool that can be equipped with any specific sensor to fulfil each mission requirements. The aim is to have an easy and quick installation for new instruments.

The design of the Navigation System is crucial. It will incorporate the presently available instruments such as acoustic positioning systems (LBL, SBL, USBL), Inertial Navigation Systems (INS) and Doppler Velocity Log (DVL), pressure sensors, etc. An on board management system is to be designed, that will allow the optimization of the operations: checklist, adjustment, mission programming, start/end.

Safety

To achieve excellence in security the submersible design and construction process will be certified and classified by Germanischer Lloyd authority.
The Mediterranean sea can be a dangerous environment due to all the waste disposed into it. To keep safety as high as possible and allow the submarine to escape from possible entanglement (net, wrecks, remains), several actions can be taken. The soft ballast (diving) tanks (600l) can be quickly emptied injecting pressurized air (700bar), determining a quick ascent. If this is not enough, a drop lead weight (500kg) can be gradually released to reduce the weight and increase the floatability. A safety buoy can be manually released from inside, reaching the surface with a 1800m long spectra rope. The two robotic arms will be ejectable in case they get stuck somehow.
The vital support system, the ascent and all the safety mechanisms will have a manual operating mode using high pressure water pumps and hydraulic pumps. Therefore, in case of emergency, all the basic functionalities will still be operative.

CONSTRUCTION

The ICTINEU 3 will be built in the Catalan Royal Shipyards, a XIII-XIV century building that hosts the Naval Museum of Barcelona. The construction will start at the beginning of 2009 and the sea trials are expected in 2010.

More information can be found at www.ictineu.net

ACKNOWLEDGEMENTS

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