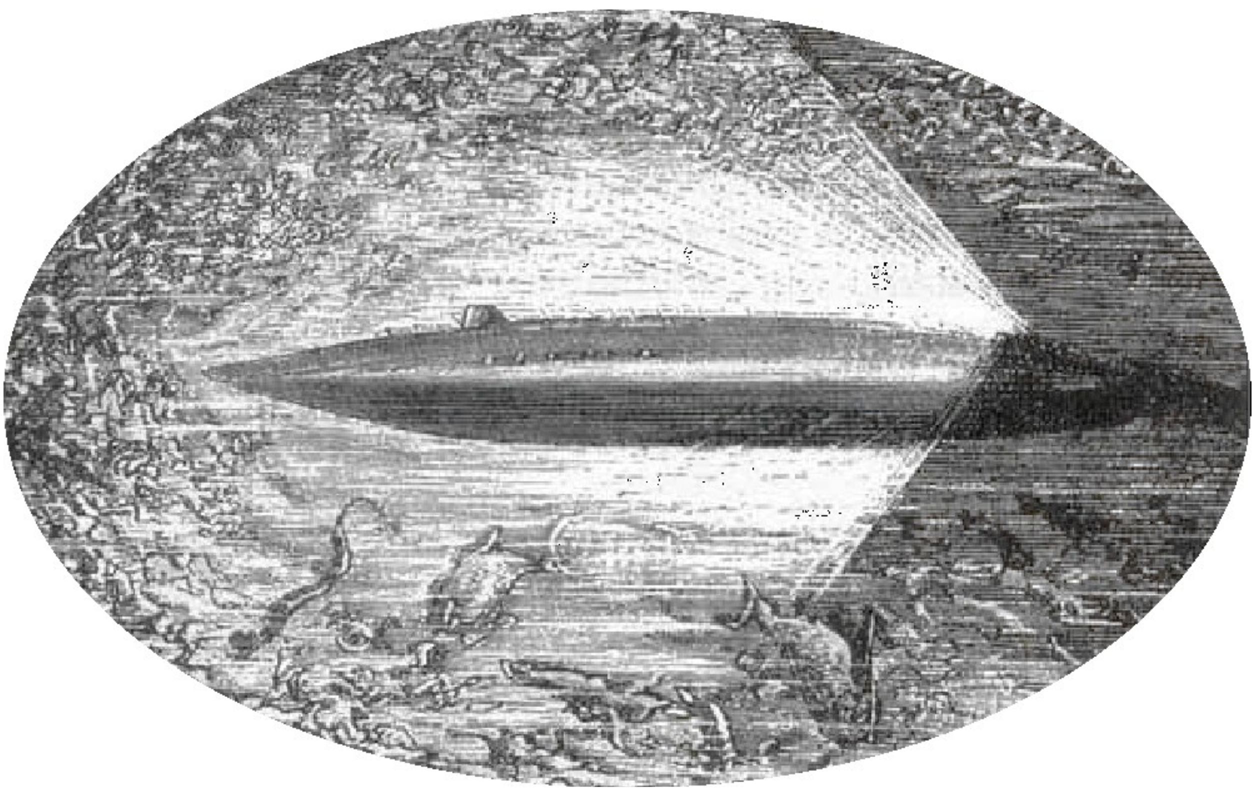
The Design of Jules Verne's Submarine *Nautilus*

Stuart Wier

Boulder, Colorado



March 9, 2015

Abstract

Jules Verne's submarine *Nautilus*, from his novel *Twenty Thousand Leagues Under the Seas*, was described by Verne in ways both detailed and consistent. Verne clearly had a particular design in mind, with exactly specified dimensions, external shape, and internal compartments. Using dimensions given throughout the novel, supported by the original illustrations, Verne's design can be drawn as plans, unambiguously, with no significant unresolved questions. His submarine description is detailed enough to permit judgments to be passed about the design's suitability for a real ship. The submarine could be built as he described – under the limitation that the batteries and engine he described did not yet exist. Verne's design incorporates important features used by actual submarine builders of his day, as well as some of the newest developments in naval architecture of his time.

The close fit of the *Nautilus*'s hull shape to its interior layout, and how all the compartments fit together, strongly suggests that Verne created actual drawings to guide his thinking and descriptions. It is unlikely that the various numerical dimensions of the *Nautilus*, internal and external, carefully given by Verne, would happen to agree by chance if his creation were simply a mental concept, or entirely verbal, written with no reference to a scaled drawings or to measurements. Verne's submarine *Nautilus* is much more than a fantasy of a novelist's imagination.

A plan (horizontal cross-section) and elevations of Verne's design are presented. The hull, 70 meters long, is purely cylindrical throughout much of its length, with a circular cross section of 8 meters. The bow and stern are simple cones, thence tapering into the cylinder. A platform or deck on top - only 0.8 meters above the waterline - features a pilot house, a recess for the ship's boat, one hatch to the interior, and a strong light for underwater illumination on a pedestal about 1.5 meters high. There is a single propeller of four blades and 6 meter diameter, and a rudder mounted on a sternpost. There is one pair of diving planes, mounted at midsection of the hull. Most of the major interior compartments are described in detail with their dimensions and furnishings. The salon has a large oval port on both sides of the hull for underwater viewing. An airlock with a door allow helmet divers to step directly onto the sea floor.

Introduction

In 1867 when Jules Verne was beginning to plan a novel about an undersea voyage, he and his brother Paul traveled to the United States on board the *Great Eastern*. The *Great Eastern* was an enormous vessel for its time, 213 meters (698 feet) long and 23 meters (75 feet) wide, the largest vessel afloat, and it incorporated some of the newest features of marine architecture. It had a double iron hull, sails, steam engines, paddle wheels, and a propeller 7.3 meters (24 feet) in diameter. Verne showed and described his keen interest in the ship, and noted details of its design, construction, and operation. Thinking of a visionary undersea vessel, he found himself traveling on the most advanced ship of his time. In the United States Verne saw other new technology, such as the large and fast Hudson River steamboats. This was a period of delight in rapid technical progress.

For the past century the submarine has played an important role in naval affairs, and in the past 50 years submersibles have become valuable in the scientific exploration of the oceans. Yet a fictional submarine, conceived decades before real submarines took up sea-going duties, remains a candidate for the most renowned: Jules Verne's *Nautilus*, from his novel *Twenty Thousand Leagues Under the Seas*.

Jules Verne is rightly regarded as a prophet of many of the inventions which characterized twentieth-century life. The novels of Jules Verne are as well known for their technical innovations as for their journeys and exotic locations. The submarine *Nautilus* and its enigmatic captain Nemo are among Verne's most famous creations. Even some who have not read Verne know that the *Nautilus* foreshadowed large modern submarines.

The *Great Eastern.*

Verne's success in foreseeing the large size and sea-keeping capabilities of actual submarines has long been recognized. Submarine design gradually approached, over decades, the fictional size, shape, and performance of Verne's *Nautilus*. Only near 1960 did submarines begin to equal the performance of the fictional *Nautilus*, 90 years after *Twenty Thousand Leagues Under the Seas* was published. Less appreciated is the technical merit of Verne's submarine design, a concept so detailed that it could be used to build a submarine, one with faults but no worse than submarines made by engineers of his day, and in many ways correctly indicating future developments. Joining technology of his day, principles of science, and some assumptions about what might be possible in the future with his creativity, Verne came surprisingly close to some aspects of modern submarines.

In the late 1860s when Verne wrote T*wenty Thousand Leagues Under the Seas,* much of the technology we take for granted was unknown or poorly known. Electric lights were experimental, and batteries and electrical motors were small, primitive, and inefficient. The relations between voltage, current, and power were not clear. The very concept of energy as a measurable quantity was little understood. Few practical electrical devices were in use, yet Verne sensed great possibilities in electricity. He was right in foreseeing large powerful electrical motors; he was wrong in hoping for large batteries supplying enormous power for days or weeks without recharge.

The original illustrations from the 1871 edition are a useful aid in support and interpretation of Verne's writing. In fact the illustration of the submarine from the original edition, copied on the title page of this report, is a completely correct indication of the shape of the hull. Though the illustrations do not always confirm Verne's descriptions, and in some cases are inconsistent even among themselves, they often verify or elaborate details in the novel. The two illustrators, Edouard Riou and Alphonse Marie de Neuville, brought in by Verne's publisher Pierre Hetzel, were obviously familiar with the novel and used it as a guide for their creations.

> “All these illustrators were collaborators and friends of Jules Verne. They met together at the same Parisian cafes; they discussed their projects and formed a team united, interdependent, and very enthusiastic.” (A. Gernoux, *Les Annales de Nantes*, 10 April 1955, quoted in Edmondo Marcucci, "Les Illustrations des Voyages Extraordinaire de Jules Verne"; Paris: *Bulletin Societe Jules Verne* 1956, p. 17.)

One of de Neuville's illustrations shows Nemo looking at plans of the *Nautilus*. Did Verne (or someone he knew) draw plans of Verne's conception of the *Nautilus*? Did he share the plans with his illustrators? I believe so, given the internal consistency of the measurements he gives of the *Nautilus*, how well it all fits together.

This is not an attempt to detail Verne's process of creation of the *Nautilus*, nor an exhaustive analysis of the *Nautilus* as a submarine. The intention is to present a complete plan with all the details and interior arrangements of Verne's *Nautilus,* as described in Verne's original French text, aided by the illustrations from the 1871 edition. Figure 1 shows my plan for the *Nautilus*, which is consistent with Verne's descriptions and which attempts to include all his details and dimensions, and also be in agreement with the original illustrations so far as is possible. Figures 2 through 4 are photographs of a 1:100 scale model of the same design. Figure 5 is an artistic impression of the plan in Figure 1. This was made by modifying a modern submarine picture found online (blogs.knoxnews.com/eder/2007/12/new_submarine _money_has_ nuke _f.html, published in 2007). I have not been able to find the creator (or the original image) of this picture.

This report expands on an article I prepared in 1982. I had long been interested in Verne's submarine, and had just discovered new translations of his novel *Twenty Thousand Leagues Under the Seas* which included Verne's technical details. The previous translation into English was so poor that Verne's submarine description was garbled beyond comprehension. In fact, even then, more than 110 years after the novel appeared, there was little or no realization in the U.S. that Verne actually had described a vessel which could be drawn on paper and evaluated in technical terms.

Reading a new translation by Mendor T. Brunetti (Signet Classics, 1969), and assisted by Walter James Miller's annotated edition of the old translation (New American Library 1976), I realized then that Verne had outlined a true design for a submarine, and one which was, in the terms of his time, a remarkably plausible projection of what might be possible. I read the translations and began to recreate Verne's plan from information in the novel, excited to see what Verne described in detail. For my own understanding of Verne's technical details, I turned to his words. I took care to translate Verne's descriptions as precisely as possible, in terms of their technical context, including nautical terminology.

Finding interest in the *Nautilus* online in 2011, I expanded my original report from 1982 and made it available on my web site. Since 2011 I have found that enthusiasts of *Twenty Thousand Leagues Under the Seas* independently created other plans of the Nautilus.

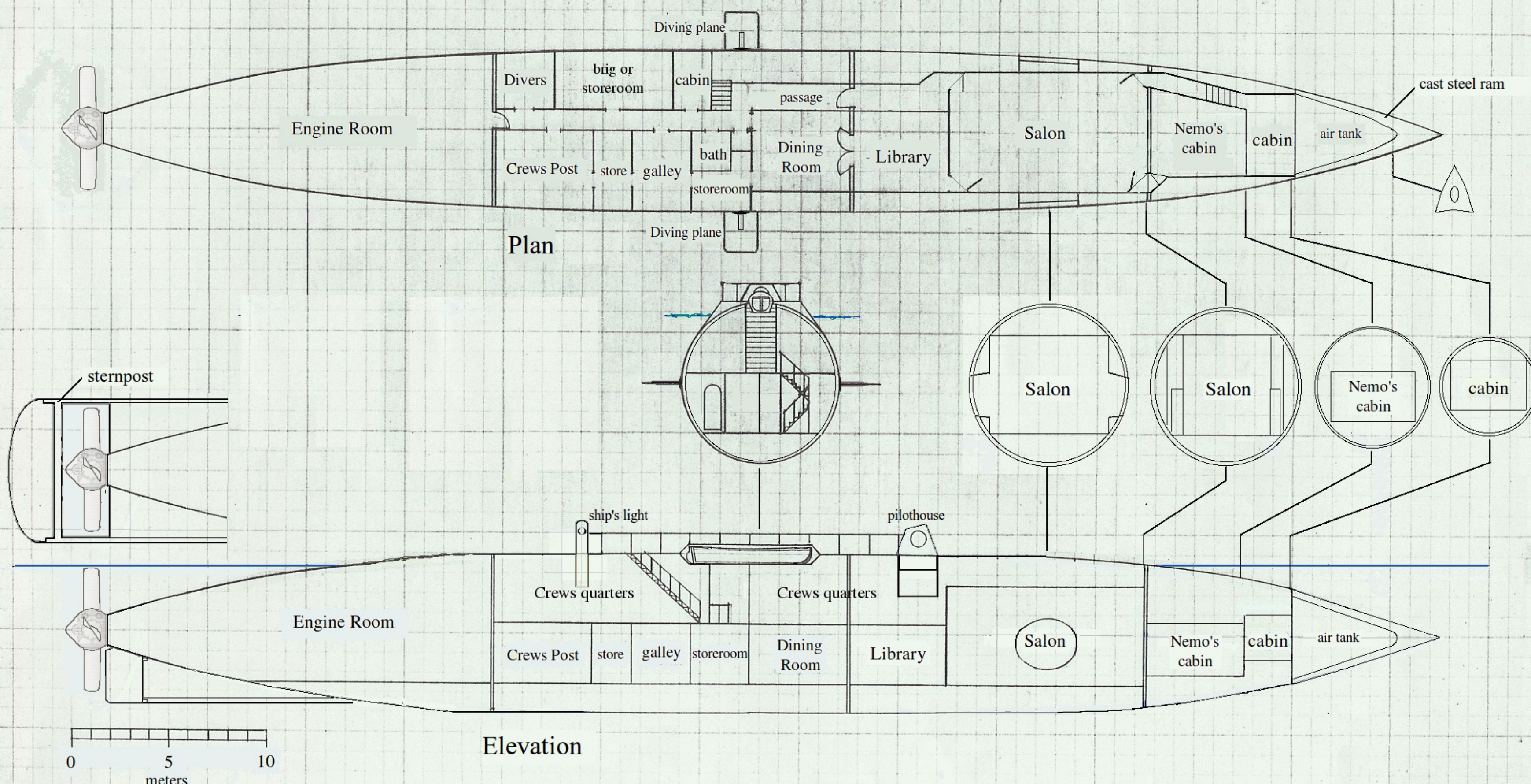
An early investigation similar to mine is that of Jean Gagneux, Chief Engineer on the French nuclear submarine *Redoutable*, who made a detailed and complete study of Verne's *Nautilus* in 1980, before my original work, but which I have only recently discovered. His findings are close to mine.

March 9, 2015

Boulder, Colorado

Jules Verne's Submarine *Nautilus*

Figure 1



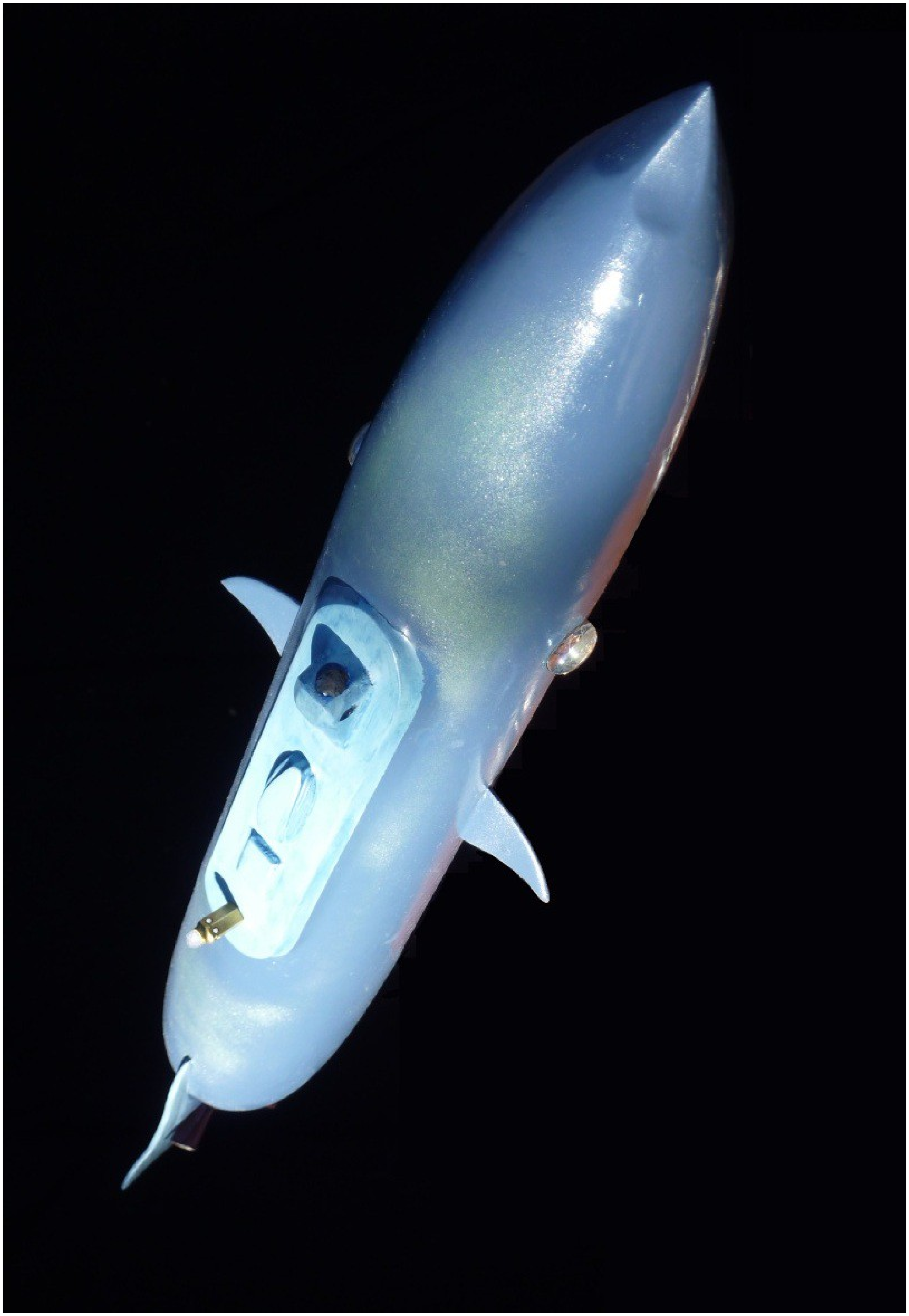


Figure 2

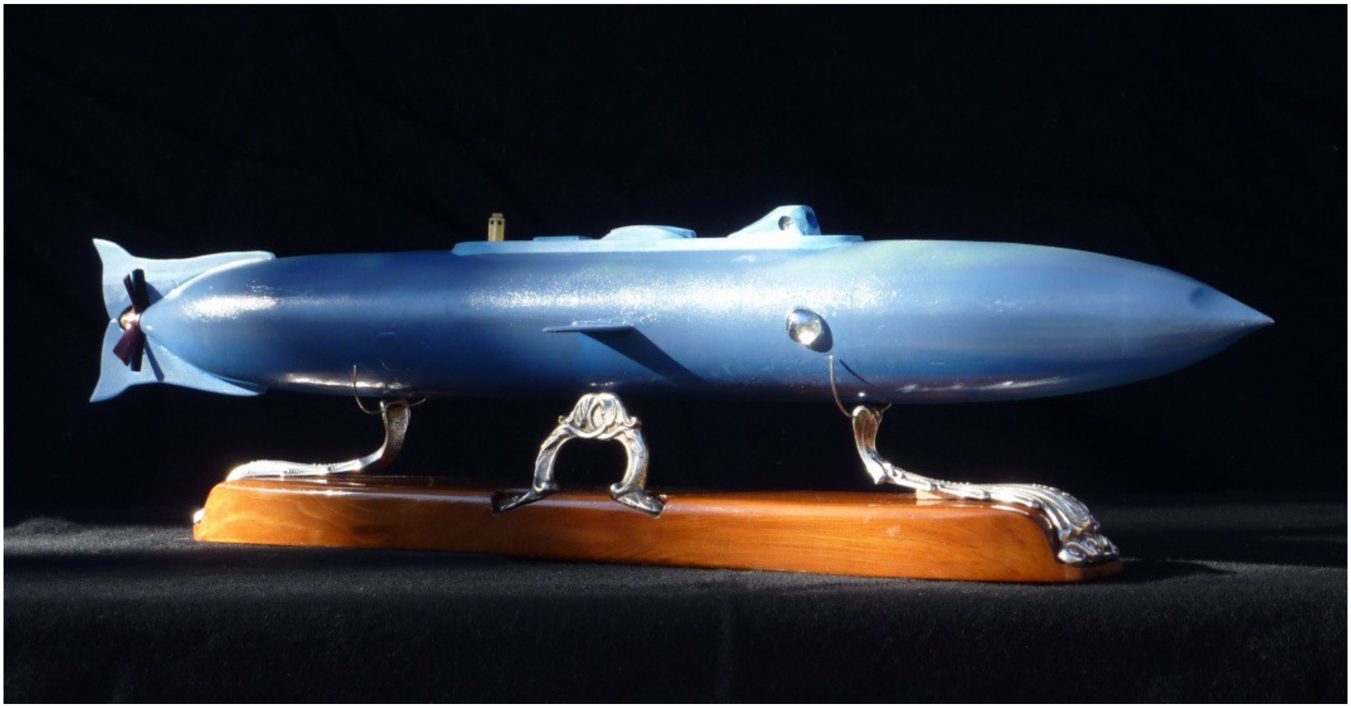


Figure 3

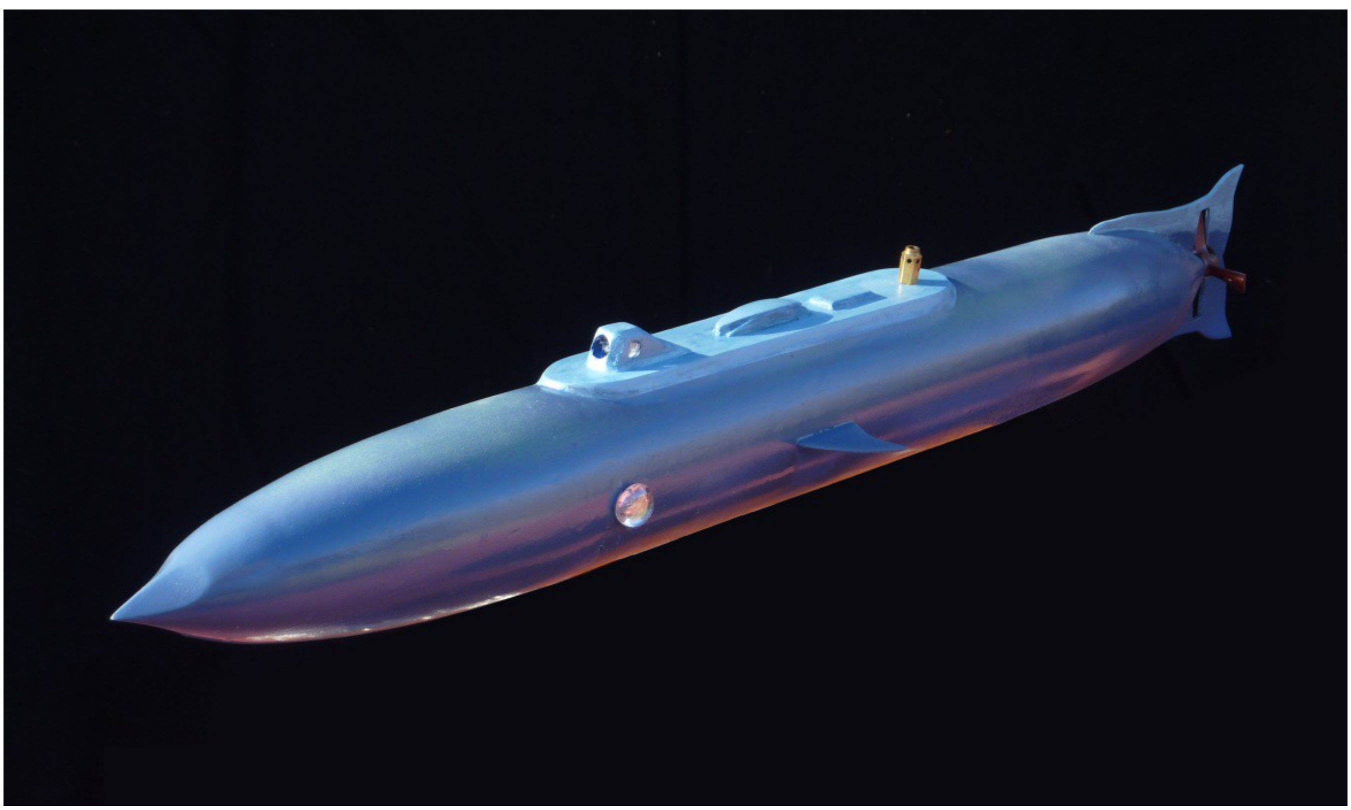


Figure 4

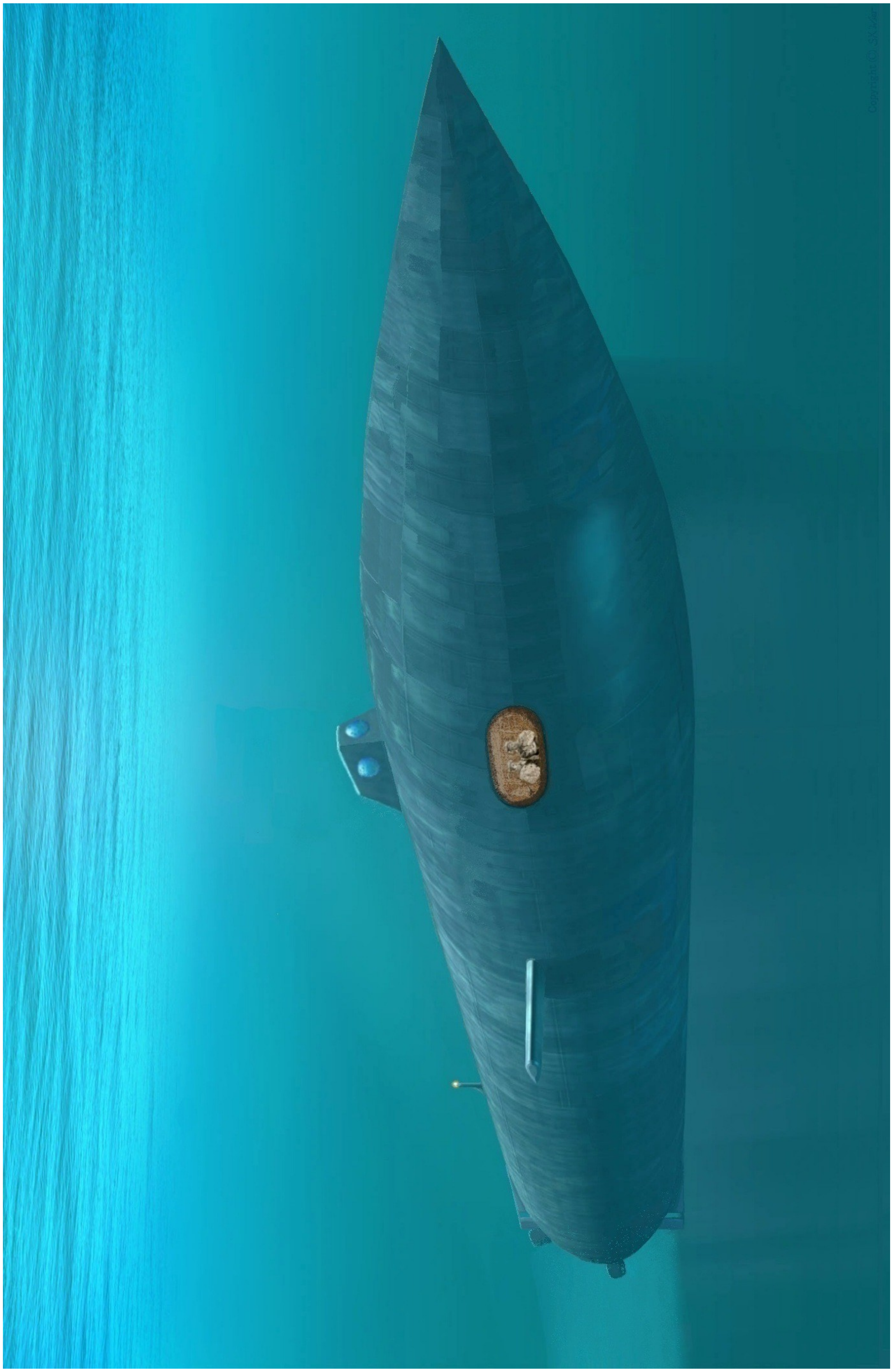


Figure 5. Artist's impression of the submarine *Nautilus* of Jules Verne. Copyright (c) 2015 Stuart K Wier

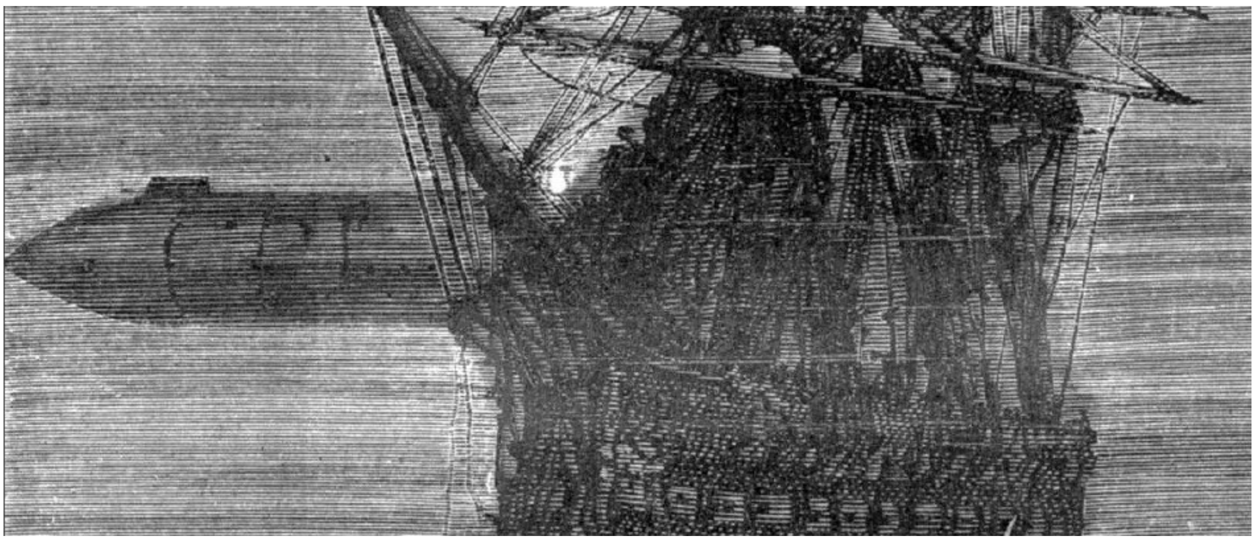
“The Enormous Iron Cylinder:” The Hull of the *Nautilus*

Jules Verne's *Nautilus* is an "enormous cylinder of sheet iron,” *l'énorme cylindre de tôle*. Is is a streamlined, tapering at each end, and mostly free of angular protrusions. The *Nautilus* is quite a large ship, 70 meters (230 feet) long and 8 meters (26.2 feet) wide. Unlike modern naval submarines the interior includes large elegant rooms furnished with fine art, museum-quality artifacts, furniture, and carpets.

Captain Nemo describes the *Nautilus* as an elongated cylinder with conical points, and says it has “a form almost like a cigar.” Note the diagram in the illustration above. Later in the novel, Professor Aronnax states the bow and stern of the *Nautilus* are *“fusiform,”* spindle shaped, and the hull can justly be compared to a long cigar. Nemo's initial description might apply to a cylinder of uniform diameter with two conical end caps. However, such a shape is not exactly spindle-shaped, or cigar-like. Nemo elaborates, saying “its lines are sufficiently long and its streamlines prolonged enough, that displaced water moves aside easily and opposes no obstacle to its progress.” The illustrations usually show a hull shape with long gradual curves.

Can we reconcile these statements, the cylinder with conical ends, and the streamlined spindle? Yes, and it is easy to do so. A central cylindrical section of the hull with uniform diameter can be smoothly joined to true cones at the ends. This is a cylinder-to-cone transition junction. The curve of the hull there in a longitudinal cross-section is an arc of a circle, and a circle can be found which is tangent to any combination of central cylinder and an end cone of any length, with no bulge or change in slope at either contact. In other words, the hull outline is smooth. Appendix A shows some combinations of conical end sections and circular arcs, some various possible dimensions for the cylinder-to-cone transition junction, which smoothly join the cones to a central cylinder of 8 meters diameter.

The original illustrations frequently show a hull with a curved shape fore and aft; none have purely conical ends, which would appear with a profile outline showing only straight lines. However there are illustrations showing the hull in profile with two different lengths of the curved hull sections, at odds with each other: one has long tapers or sharper ends and the other has more blunt ends, such as the next picture, a detail from an original illustration showing the *Nautilus* passing a sinking ship. The illustration on the title page of this report is the more cigar-like form. Either of these is consistent with the hull description, but not always with interior details.



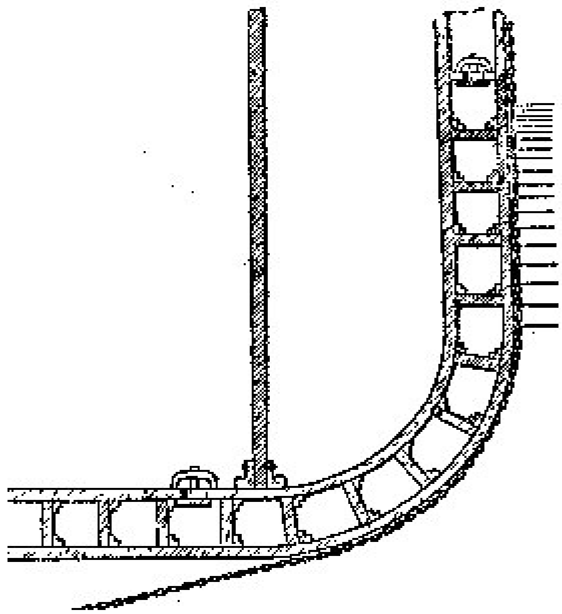
My plan and model of the *Nautilus* (Figures 1-4) agrees with all of Verne's measurements and descriptions. This hull shape and size encloses the interior compartments of the *Nautilus* described by Verne. The hull in Figure 1 is purely cylindrical in its central 30 meters (98.4 feet) of length, with a diameter of 8 meters (26.2 feet). This is the minimum length of any 8 meter cylinder which can contain the forward end of the salon in the double hull. The salon and double hull are described in detail below. Any shorter centrally-positioned 8 meter diameter cylinder cannot fit the salon inside. Since it is circular in cross section the maximum beam (width) is 8 meters and the distance from the top deck to the bottom of the hull is 8 meters.

Five meters (16.4 feet) at each end of the hull (Figure 1) are true cones, each with a base diameter of 3.24 meters (10.6 feet). Joining the central cylinder to the end cones are two parts of the hull which are curved in profile, each 15 meters long. The outer hull curve in a central longitudinal cross-section is a circular arc of radius 48.5 meters (159 feet). This figure is used only in drafting; that length is not seen on the plans.

This hull shape is intermediate between the most streamlined hulls and the blunt hulls in the novel's illustrations. A hull with a longer cylindrical section would also fit Verne's interior measurements, but any more streamlined shape will not. Note that there is no reason at all that Verne's hull shape would be anything other than a regular circular cylinder in much of the length, smoothly joining simple cones at the ends. There are no swellings, bulges, ridges, polygonal shapes, protruding rams, or saw-edged fins. As much fun as those might appear,

The finish of the outside of the hull also has two descriptions, again somewhat at odds with each other. When Professor Aronnax first boards the *Nautilus* floating on the surface he says the hull “was smooth, polished, and not imbricated," imbricated meaning showing overlapping edges in a regular pattern. He also says it seemed to be built of bolted plates. Much later he says, "these sheet metal plates, lightly imbricated, resembled the shells of large terrestrial reptiles." The novel's original illustrators consistently show delineated and possibly overlapping plates with lines of bolts or rivets, typical of metal hull construction of the time. It seems Verne imagined the *Nautilus* had a hull of smooth or polished metal plates, but also showing bolts or rivets, with lines or overlaps at the edges of the plates. This form of hull construction survived to World War I and beyond.

The hull is made of two shells, one inside the other, connected with "T irons." Nemo calls this a "cellular configuration" which has "extreme rigidity" so that the hull resists pressure like a solid block. It had better – the *Nautilus* routinely cruises at depths of thousands of meters. The shells are made of sheet steel, with a density of 7.8 grams per cubic centimeter. The outer hull or shell is five centimeters thick (1.97 inches). This is similar to the thickness of the steel pressure hulls of many modern submarines. The keel is 50 cm (20 inches) high and 25 centimeters (10 inches) thick.



There is no indication of the thickness of the inner shell, or of the width of the double hull. But Verne's voyage on the *Great Eastern* may have formed his ideas in this matter. The *Great Eastern* like the *Nautilus* had a double hull. The drawing above is half of a transverse section of the double hull of the *Great Eastern* (from *Scientific American*, Dec. 27, 1862), and we can use this design as a guide to what Verne might have regarded as a good design for the hull of the *Nautilus*. (The chain in the drawing is not part of the hull.) The total thickness of the *Great Eastern's* double hull was 0.86 meters (2 feet 10 inches). Since the *Great Eastern* was close to three times larger than the *Nautilus* in linear dimensions, the same hull structure scaled down to a third for the *Nautilus* would be about 0.29 meters (11 inches) thick, an initial estimate of what Verne may have had in mind. Verne's *Nautilus* also has watertight transverse bulkheads for safety, another new idea he may have copied from the *Great Eastern.*

More recent actual submarines often had or have double hulls as well. But whereas Verne's double hull made up one pressure-resisting hull, actual submarines have a pressure hull on the inside while the outer hull is not pressure resisting, allowing full pressure seawater inside, to provide streamlining and covering for machinery outside the pressure hull which can be exposed to sea water pressure. Modern outer hulls may be about 2 cm thick (1 inch) and the inner pressure hull about about 5 cm thick (2 inches) based on published data for the Russian submarine *Kursk*. The *Kursk* had a 2 meter separation between the outer and inner hulls.

The maximum depth reached by the *Nautilus* in Verne's novel is 16,000 meters (52,480 feet or close to 10 miles), in Part 2, Chapter 11, subjecting the hull to a pressure of 1600 atmospheres or 10 metric tons per square inch (1.6 metric tons per square centimeter). This depth far exceeds the depth capability of any large submarine, and exceeds the deepest part of the ocean, now known to be about 10,900 meters.

The bow of the *Nautilus* is used as a ram to damage or sink ships. Describing the construction of the submarine, Nemo mentions the ram as special forging, saying it was made in Motola, Sweden. Iron and steel forgings are still made in Motala. It appears that Verne imagined the ram as a single steel casting several meters long, which made up all or part of the forward conical section of the hull. There is no mention of a protruding ram or harpoon.

In the early part of the novel, Aronnax mentions a Cunard steamship, the *Scotia*, which collided accidentally with the *Nautilus*, suffering a hole like an isosceles triangle 2 meters across, as if made by a cutting machine. So the point seems to be be cut or tapered to make three edges, modifying its basic conical shape. Incidentially the *Scotia* was a real steamship of Verne's time, which carried Theodore Roosevelt and his family to Europe in the same year in which it supposedly was struck by the *Nautilus*, but without encountering submerged obstacles. Such details exemplify how Verne used actual circumstances of his time to provide a basis in reality.

One measure of the size of a submarine is its displacement. Displacement of a submarine is measured by the volume of water it occupies, typically when fully submerged, or by the weight of seawater in that volume. One cubic meter of *pure* water weighs exactly one metric ton, 1000 kilograms (2205 pounds), and by chance is also close to one English "long" ton (2240 pounds, 20 times the antique weight unit "hundredweight"). So when dealing with pure water a cubic meter of water (a volume) is also one metric ton (a weight). Verne uses this equivalence.

Nemo says the *Nautilus* displaces "1500.2 cubic meters, which means when entirely submerged it displaces or weighs 1500 cubic meters or tons." Verne made two errors here. A cubic meter of fresh water weighs a metric ton, but a cubic meter of seawater weighs typically 1.025 times more. The Nautilus is a vessel of the oceans, not of fresh water. Only 2.5 percent more, but that is significant if you build a submarine. If your submarine is under weight by 2.5 percent, it will never submerge.

A much larger error is that, despite Verne's usual precision, his stated displacement for the *Nautilus* is simply impossible. The central cylindrical section, 8 meters in diameter and 30 meters long, as in Figure 1, alone has a volume of 1507.96 cubic meters, leaving less than nothing for the other 40 meters of the hull length. It is not possible in nay way to design a hull which fits Verne's numerous other measurements and also has 1500.2 cubic meters volume. The design in Figure 1, which matches all of Verne's other specifications, has a submerged displacement very close to 2500 cubic meters (in weight of seawater, about 2562 metric tons). The similarity of the numbers 1500 and 2500 suggests that Verne's use of 1500.2 cubic meters in place of 2500 was a simple case of a copying mistake somewhere along the line, with one numeral in error.

This is a large submarine. Verne's *Nautilus* is ten times larger than any real submarine before 1900. The common German Type VIIC U-boat of WWII was 865 tons. US fleet submarines of World War II were mostly about 2400 tons. Modern fleet ballistic missle submarines are far larger than 2500 tons.

Surfaced, a submarine displaces (weighs) less; water pumped out of ballast tanks is replaced with air and the lower weight of the entire vessel causes it to float and emerge above the sea surface. The top deck of the floating

Nautilus is 0.8 meters above the water level, one tenth of the top platform to keel separation of 8 meters. Nemo says, “I wished, when surfaced it would emerge only one tenth. Consequently in these conditions it must displace no other than nine tenths of its volume...” This would be true if the *Nautilus* were rectangular in cross section, a long square box, but being circular, less than one tenth of the volume is occupied by the top tenth (0.8 m) of the 8 meter circular cross section. The design in Figure 1 reduces the displacement by 6.2 percent, 155 cubic meters out of 2500, when the deck is 0.8 meters above the water, including the pilot house, hull enlargement to form the deck, longboat, and searchlight.

These errors are simple mistakes which do not alter the novel's essential quality. They are at odds with Verne's occasional preoccupations with much smaller technical adjustments, such as Nemo's discussion of the effects of the compressibility of sea water, a far smaller effect than density variations between fresh and salt water, which Verne completely missed. But all these technical details by Verne show his desire to build on reality.

There is a flat deck or platform on top of the *Nautilus*; the platform lies eighty centimeters (31 inches) above the level of the sea when the submarine is floating on the surface. Professor Aronnax says the hull itself forms, in its upper part, a sort of horizontal platform. Several illustrations show the riveted plates of the pressure hull forming the flat surface. Later practical submarines had upper decks made of gratings of metal or wood attached to pressure hulls maintaining circular cross sections throughout. A removable railing can be installed around the deck.

“An Excellent Craft”: The *Nautilus*' Longboat

There is a longboat, “light and unsinkable,” for excursions and fishing. The boat is stored in the middle of the deck, half sunk in a recess in the ship's hull, forming a bulge of some kind above the deck. On one occasion Aronnax said he was seated on the protrusion made by the hull of the boat. Several of the original illustrations (as next) show a bulge on the hull which is either the boat, or a cover over the boat. The boat can hold at least ten persons: six oarsmen, one at the tiller, and three passengers in the stern. A length more than 5 meters (16 feet) is called for. Despite this size, Aronnax says two men can remove the boat from its recess and launch it in the sea.

One illustration (shown below) shows a large boat sitting upright behind a large coil of rope, and it appears to be a typical wooden lapstrake or clinker-built boat of Verne's time. The entire illustration appears to have been inspired by fishermen on a beach, not by the *Nautilus*. Nemo describes his boat as having unique features, nothing like those of a wooden boat. His boat is

“...entirely decked over, absolutely watertight, and held in place by solid bolts. This ladder leads to a hatch in the hull of the *Nautilus*, which corresponds to similar hatch pierced in the side of the boat. This double opening admits me to the boat. Someone closes the hatch of the *Nautilus*, and I close the other in the boat, by force of pressure. I release the bolts and the boat rises with tremendous speed to the surface of the sea. Then I open the panel of the deck, carefully closed until then, I step the mast, I raise sail or take my oars, and go on my way.”

This indicates that the boat's compartment does not have a separate cover – if Verne described the submerged launching of the boat completely. Verne fails to suggest how a boat large enough to hold ten men, covered to have a watertight interior, and strong enough to resist the depths reached by the *Nautilus*, can be light enough for two men to remove from its position 'half-sunk' in a recess in the hull. The boat of the *Nautilus*, and its operation as described, is fascinating, but scarcely practical.

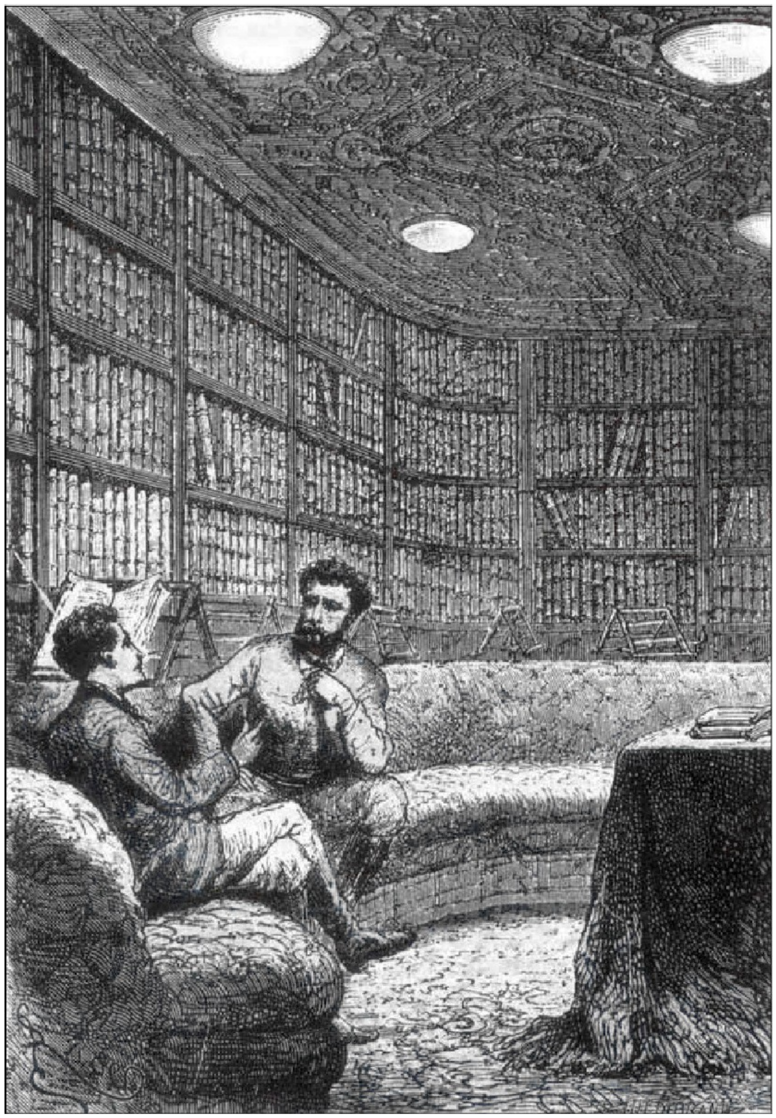
“All the forward part of the submarine”: Interior Layout and Furnishings

The dining room.

Entry to the interior of the *Nautilus* is by a staircase from the top deck, closed on top by a panel, and ending below near the center of the submarine. This stair could be quite steep, as is often the case on ships, such as the stairs shown in the illustration of the engines of the *Great Eastern* in the the final part of this report, stairs which Verne himself may have climbed. Verne terms the central stair a “ladder” three times; the steepness of such a marine stair easily explains the use of that word. French – like English – needs a special word for steep marine stairs.

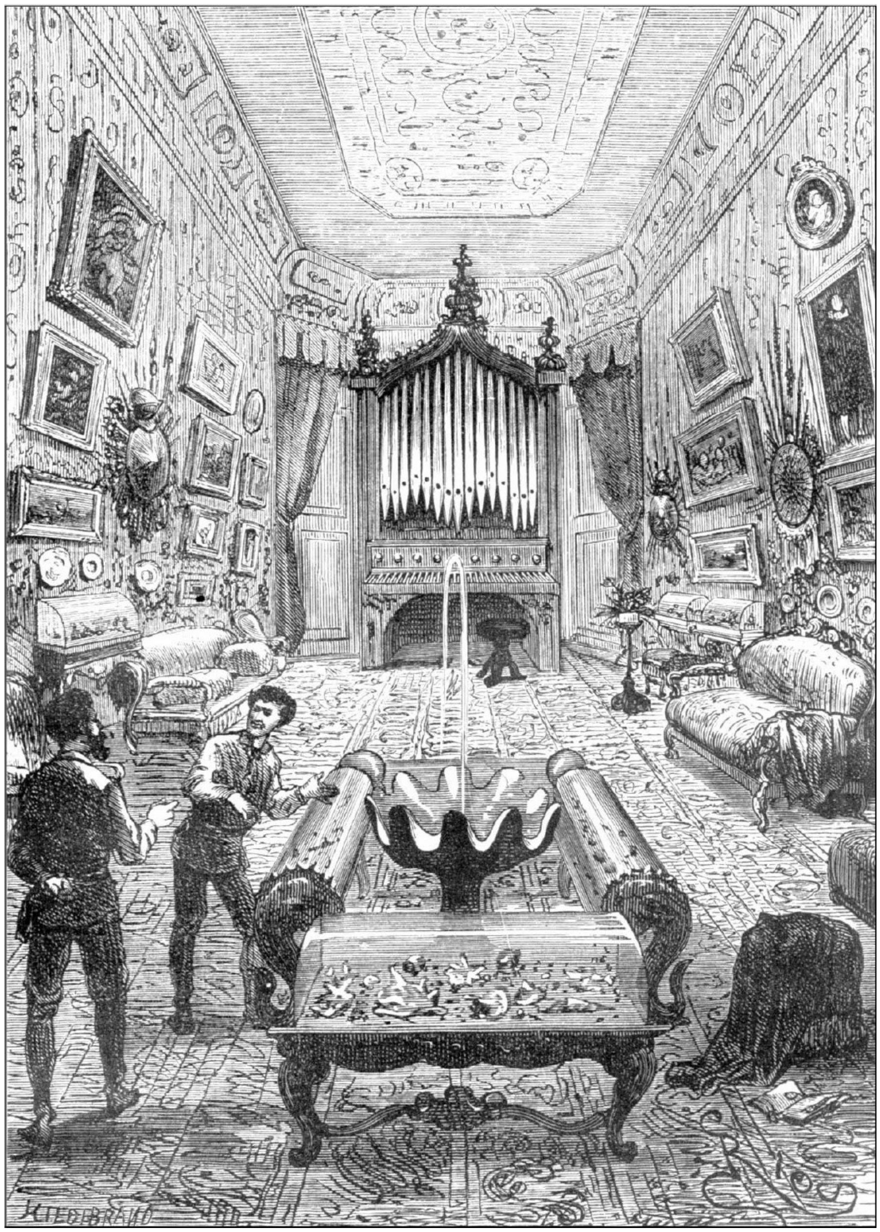
The interior of the *Nautilus* includes several large ornamental compartments. Aronnax gives the exact dimensions. Going forward from the center of the ship to the bow there is a dining room 5 meters (16.4 feet) square, then double doors leading to a library of the same size. Forward of the library is the grand salon, rectangular, 10 meters (32.8 feet) long, 6 meters (19.7 feet) wide, and 5 meters (16.4 feet) high. The salon occupies the full width of the hull but the dining room and library do not.

The dining room has tall oaken sideboards at both sides of the room, and sparkling on their shelves are rows of faïence, porcelain, and glass of incalculable value. Silver-plated dinner service shines under rays of light pouring from fixtures in the ceiling.



The library.

This illustration depicts the library of the *Nautilus* exactly as Verne describes it. There are dark bookcases, ornamented with copper, lining the walls, large divans upholstered in maroon leather, and a central table. A double door in the aft partition, not shown, leads through a watertight bulkhead into the dining room. Another door forward leads to the salon. The light, movable reading stands or supports for books are a nice period touch, as mentioned in the novel. The library holds 12,000 volumes. Illumination is by four frosted electric half-globes in volutes of the overhead or ceiling.

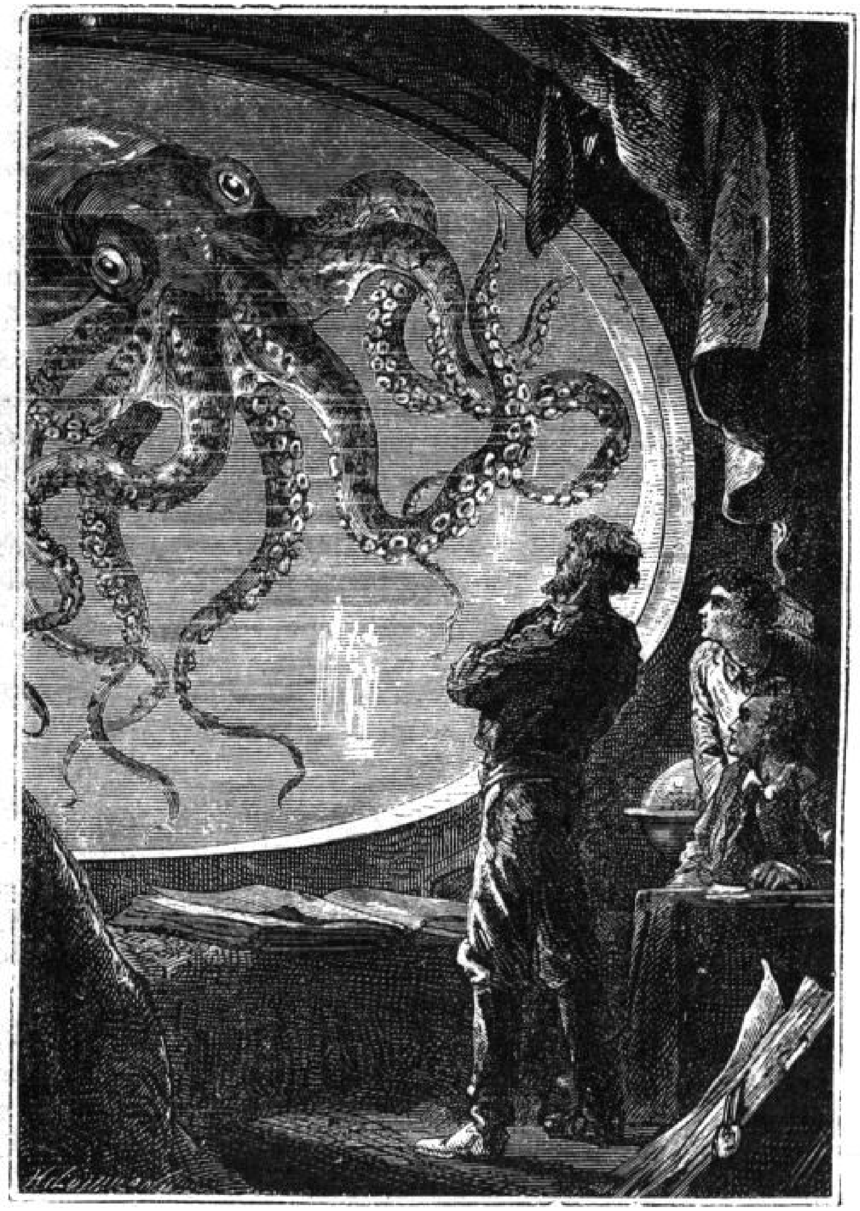


The Salon

The salon is splendid. Its furnishings account for more than half the cost of the *Nautilus*. Thirty paintings by great masters cover the walls, from the Renaissance to 19th-century France, but no impressionists, of course. Small copies of marble and bronze statues from antiquity stand in corners. There is an organ and music for it; the earliest composer is Mozart and the most recent Wagner. Nemo has no Bach fugues to perform on the organ. There is a trained naturalist's collection of wonderful marine specimens, and a fountain, of all things, which falls into the shell of a tridacna clam some 6 meters (20 feet) around, or about 2 meters (6 feet) across, an extraordinary shell in its own right.

The salon has "cut corners," as shown in the illustration above. Aronnax says "doors pierce each cut corner of the salon." Indeed there are four doors in each corner of the salon: one from the library (aft), one from Nemo's cabin forward, one leading to a passage going aft, and one leading to a short passage going forward, alongside Nemo's cabin, to the cabin used by Aronnax. The illustration shows two of those four doors, in the cut corners.

The salon as illustrated looks like the drawing room of a Scottish baronial residence of the Victorian period, even to the trophies of arms on each side wall. The proportions of this drawing are a little wrong; the salon is wider than tall.



A Window of the *Nautilus*

Despite what is in effect a world-class collection of art and artifacts, the most memorable feature of the salon are the windows which allow the passengers of the *Nautilus* to gaze upon the living marvels of the sea. There are two windows, one on each side of the salon.   The original illustrators depicted a salon window three times, always as an oval about 2 meters high by 3 meters long (about 6 by 10 feet). Verne does not indicate any size, and only says they are “oblong openings.” Metal panels, operated by unseen machinery, can cover the windows. Oddly the first illustration of the salon shows no windows which are dramatically illustrated elsewhere.

Forward of the salon is Nemo's cabin, 5 meters (16.4 feet) fore and aft, and then an “elegant chamber” used by Aronnax 2.5 meters (8.2 feet) fore and aft. The widths are not given. Nemo's cabin is severely plain. Forward of

Aronnax' cabin, the hull extends another 7.5 meters (24.6 feet) to the bow, the point of the ram, including a reservoir of air. There is a passage connecting Aronnax's cabin to the salon, passing Nemo's cabin, and another passage from the salon to the central stair, passing to one side of the library and dining room.

Big trouble at the central staircase, on the upper deck.

Going aft from the center of the ship is "a sort of well" with a vertical ladder leading up into the boat, then the central staircase leading to the upper interior deck and from there to the top deck. Next is a cabin 2 meters long (6.56 feet) along the the axis of the submarine occupied by Conseil and Ned Land. Nearby is the galley, 3 meters (9.8 feet) long, placed between large storerooms. These compartments all fit best if located on both sides of the central corridor, as shown in Figure 1. The galley stoves are electrical, and there is an electrical distillation apparatus to make potable water. Near the galley is a bathroom with hot and cold running water.

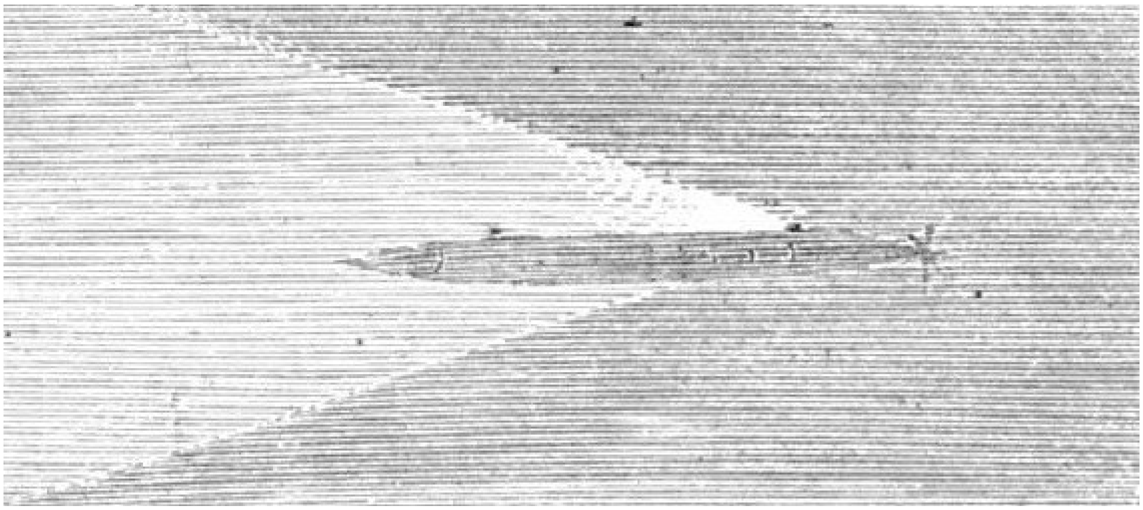
Aft of the galley Aronnax noted what he called the crews' post or berth, 5 meters (16.4 feet) long, but the door was closed and he could not see its arrangement. It seems feasible that this compartment is the crew's mess, being next to the galley and too small for all the crew's berths. Across from the galley is the compartment where Aronnax, Conseil and Ned Land were detained when first boarding the *Nautilus*, 20 feet (French *pieds*) long and 10 feet wide. Its door is about 10 meters (33 feet) from the dining room. Aft of this cabin is the outfitting room for divers, with a dozen sets of diving suits, and with a door from the outfitting room into an airlock chamber. The airlock has a door in the outer hull, a door which Verne once calls a 'double door.' Divers walk out of the submarine and step onto the sea floor, rather than dropping through a hatch. Perhaps even side by side.

Behind a watertight bulkhead, aft of the crew's mess, the divers' outfitting room, and the airlock, is the engine room, a single large compartment 20 meters (65.6 feet) long. The engine room is described in the next section.

A note about the lower deck's level in the hull: if it is placed 1.5 meters above the bottom of the hull, as in Figure 1, there is enough space below for main ballast tanks, and the center line of the hull is along the center line of the salon. The salon just fits inside the hull in Figure 1, but it must be centered on the axis of the hull to fit. Nemo's cabin must be raised a few steps (about 0.75 meter) to fit inside the hull, and the forward cabin needs to be a few steps higher still (another 0.75 meter).

As shown in the plan in Figure 1, there is considerable space inside the hull, in effect an upper interior deck, not described by Verne. If he gave any thought to this area I have no idea. It is the obvious place for crew quarters. The space available is 18 m (59 feet) long, and more than 5 m (16.4 feet) wide and 2.5 m (8.2 feet) high. The crew is scarcely mentioned in the novel, and almost nothing is said about their accommodations or activities. There is also an unstated mystery about where Nemo lives when he disappears for days at a time, while his three guests have free access to the large ornate compartments on the lower deck, and even to Nemo's cabin. At least there is plenty of room in the *Nautilus* where he *might* be.

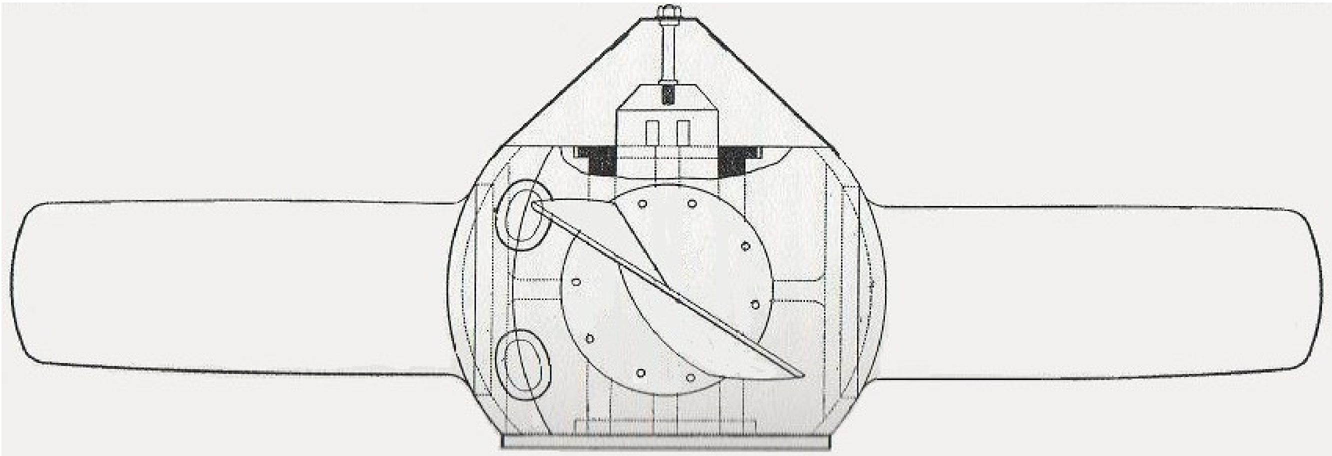
"The dynamic power of my engines is nearly infinite": Power, Propulsion, and Control



Despite a popular notion that Verne's *Nautilus* had some sort of futuristic power supply, such as atomic power, Verne based his technology on what was known in his day. The power supply is chemical batteries. Verne realized that the actual batteries of his day were far from adequate, as batteries remain today, but suggested they might be greatly improved. Nemo says he uses "large and powerful" Bunsen batteries rather than Ruhmkorff batteries which are less powerful. Nemo has improved the Bunsen battery by using elements of a sodium-zinc amalgam in place of zinc alone, which Nemo claims doubles the "electromotive force" of the batteries (what we call today the voltage). Perhaps Verne was unaware of the explosive property of sodium in contact with water. Nemo extracts sodium from sea water on a remote island, where the process is fueled with sea coal. The new sodium would recharge Verne's hypothetical batteries, which seem to last for months between charges.

The electricity, generated in the forward part of the engine room, powers large electromagnets which set in motion a system of levers and gears which transmits movement to the propeller shaft. In Verne's day development of both batteries and electrical motors was primitive. Not until late in the 19th century did design of rotary electrical motors achieve their present level of high efficiency, due to the efforts of mathematically trained engineers such as Charles Steinmetz of General Electric. Verne seems to have in mind a reciprocating engine, something like a classic steamship engine with vertical steam cylinders, where electromagnets fill the role of the cylinders. At that time, such a design seemed perfectly plausible. As it turned out, rotary electrical motors are much better.

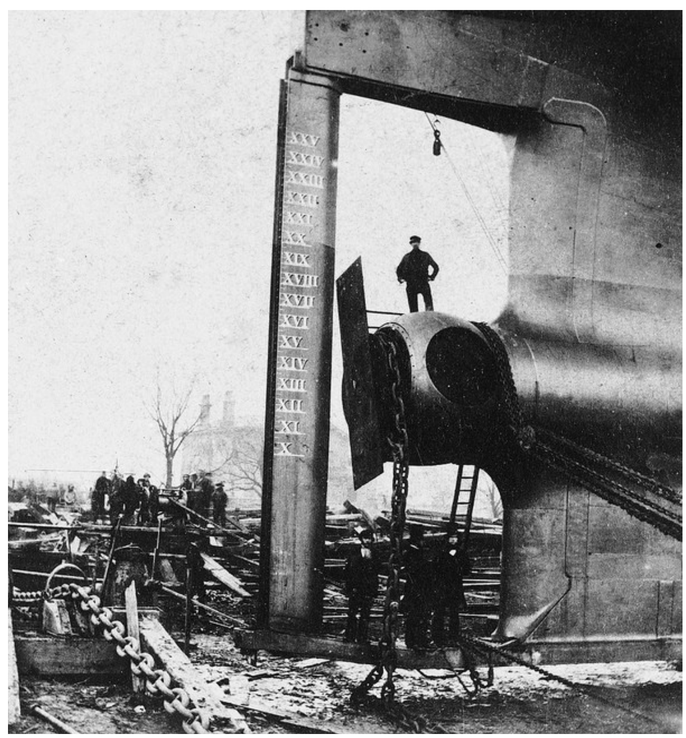
The propeller has four blades, a diameter of 6 meters (19.7 feet), two meters less than the full diameter of the hull, and a pitch of 7.5 meters (24.6 feet). The propeller in the diagram shown below is that of the *Great Eastern*. That propeller presumably represents good design practice at the time Verne wrote. The *Great Eastern*'s propeller weighed 36 tons; reduced to 6 meters diameter it would weight 20 tons. The text of the novel says the propeller can make 120 "turns per second," which must be a typing mistake. That high figure is essentially impossible; even if you had the power to turn such an enormous propeller that fast, the result would be cavitation, frothing the water into steam bubbles, and little forward motion. Verne surely meant 120 turns per minute, still three times the rotation rate of the *Great Eastern*'s propeller. At this rate the propeller would give a speed of, I estimate, 22 to 33 miles per hour, or 19 to 29 knots, a plausible speed for a high-powered submerged submarine. There are some wholly unworkable characteristics of Verne's *Nautilus*, but the propeller is about right.



Propeller of the *Great Eastern*. Diameter 7.3 meters (24.6 feet); weight 36 tons.

The picture at the top of this section is a small detail from one of the original illustrations. Despite the small size and having suffered the indignities of being turned into an engraving, this is a crude but effective impression of the outside of the *Nautilus*, and the only illustration to show the large, four-bladed propeller. The illustration reproduced on the title page of this report also shows a hint of the propeller, which was perhaps more distinct in the artist's original drawing before it was made into an engraving for printing.

To steer, the *Nautilus* has an ordinary rudder with a large blade “fixed on the back of the sternpost.” It is controlled in the usual way, with a ship's wheel by a helmsman, in a pilot house. None of the illustrations show the rudder so there is no indication which of several possible shapes and arrangements Verne might have had in mind. Figure 1 shows two possible rudder arrangements. One with the rudder aft of the propeller is like the rudder of the *Great Eastern*, attached to a sternpost, as shown in the photograph at the right. In this scene the rudder blade and propeller blades are not attached. The human figures indicate the massive size of that ship, but the propeller, rudder, and opening are only some 22% larger than the corresponding parts of Verne's *Nautilus*. The French submarine *Plongeur*, which was launched shortly before Verne wrote *Twenty Thousand Leagues Under the Seas*, had the same rudder design. I am inclined to think Verne had such a rudder in mind, even though it is not exactly described, or shown in the illustrations. This photo strongly suggests the character of the stern of of the *Nautilus*.



The pilot house is “a little like the pilot houses” of Mississippi River and Hudson River steamboats, 6 feet (French *pieds*) on a side, which rises above the deck of the *Nautilus*. Ports with lens-shaped glass in the four walls permit the helmsman to see in all directions. The windows are 21 cm (8.3 inches) thick. Three men, at least, can stand in the pilot house at a time. The original illustrations show the exterior of the pilot house many times and in many sizes, some comically small, but the text is clear. The illustration shown below is consistent with Verne's description, except for its lack of a porthole in the side. When Verne was beginning to think of this novel he visited New York City and traveled on a Hudson River steamer. His explicit use of the American term 'steamboats' is another sign he was consciously using ideas suggested by American steamboats in his pilot house.

The Pilothouse

To dive, Nemo says he can move the *Nautilus* in the vertical with inclined planes attached at the center of flotation, whose angle is controlled with levers. Apparently Verne had the idea that the submarine would descend or ascend on an even keel, along a path at an angle set by the inclined planes. In a dramatic scene Nemo sets the inclined planes to vertical, and the submarine rises, on a level keel, at a rate of 1 league (2.5 miles) per minute, or 150 miles per hour, vertically. One wonders what happened on reaching the surface. Verne had some odd ideas about hydrostatic pressure which explain the extreme force needed for such vertical speed. For example he says the pressure of the sea would obliterate footprints in the soft sea floor.

Such a centrally located pair of diving planes appealed to submarine designers in Verne's day, but they produced little or no control. Some early submarines surprised and alarmed their crews with sudden changes in pitch and depth, in one case diving so suddenly that the submarine was stuck for a time in the mud of the bottom. The solution is diving planes near the stern, and additionally another pair on the forward part of the hull. This arrangement allows positive control of pitch. Modern submarines use an angle down or up when diving or rising.

Also aiding diving are ballast tanks holding 150 tons of water (presumably Verne meant 150 cubic meters), placed in the lower part of the *Nautilus*. There is enough space for these tanks in the plan of Figure 1, below the lower deck. When the tanks are filled the *Nautilus* attains neutral buoyancy. As indicated above, the tanks would actually need to hold about 155 cubic meters rather than 150 for the deck freeboard of 80 cm when surfaced. Two of Verne's errors canceled each other out to give almost exactly the correct size for the main ballast tanks.

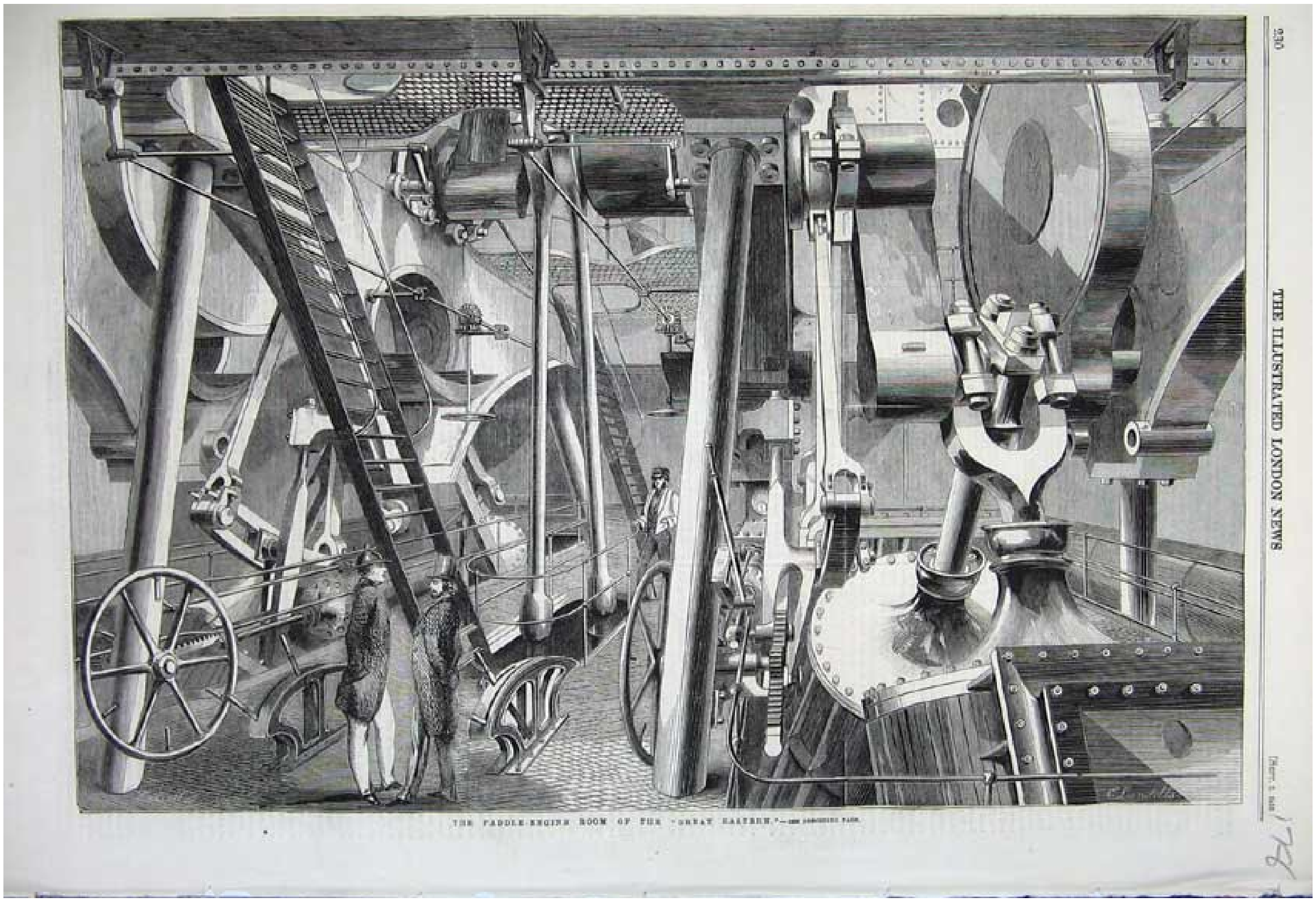
The ballast tanks are emptied with powerful pumps, rather than the compressed air used in practical submarines. The pumps can shoot jets of water 120 feet in the air, when the submarine is surfaced. There are reservoirs of compressed air, but they are used only for emergencies, apparently for breathing air.

There is some question about the top speed of the *Nautilus*. Cruising some 2000 miles during a period of one week (Part 1, Chapter 18), the average speed was about 12 miles per hour. Once Aronnax says the speed was not less than 35 miles per hour (Part 1, Chapter 23). Nemo claims a top speed of 50 miles per hour. The highest speed achieved in the novel is 40 miles per hour (about 64 km/hour) when the submarine was fleeing, trapped under Antarctic ice, and the passengers are on the point of suffocation. All these “miles” are the French *mille*.

To light the sea underwater, there is a strong light or 'ships lantern' in an exterior enclosure at the aft end of the top deck. The enclosure is tall enough for Nemo to rest his elbows on it while he gazes on the surface of the ocean (perhaps 1.2 m or 47 inches) and the sides must be pretty nearly vertical, also. The windows are Fresnel lenses with annular rings, like windows in lighthouses. Fresnel lenses can be circular, square, or cylindrical, surrounding a light, so Verne may have had any of these in mind. This light illuminates the sea all around the *Nautilus* so it is more a flood light than a search light with a narrow beam. The light source is an electrical carbon arc in a vacuum, with graphite points. The exterior light or lantern of the *Nautilus* combines the best technology of Verne's day.

Verne had an idea, or a hope, that the deep sea would be clear and the *Nautilus* would sail though a transparent medium like an airship through the atmosphere. Several times the light from the *Nautilus* illuminates the sea for half a mile or more. The first time Aronnax looks out the windows of the salon, the sea was distinctly visible for a mile around the *Nautilus*. In such a world sonar would be needed, but a strong light would be necessary.

Both the pilothouse and the light enclosure can be pushed down into the hull of the *Nautilus*, by hand, leaving nothing showing above the hull. This requires the pilot house to be aft of the salon, or else it would drop down into the salon when withdrawn.



A dramatic illustration in period character showing part of the steam engines driving the paddle wheels on the *Great Eastern*. Verne traveled on this ship, and engine room tours were offered to the passengers, two of whom we see in this picture. Verne's idea for the engines of the *Nautilus* may have have been reciprocating like these engines, rather than rotary; he may have been strongly impressed by the size and power of these actual marine engines. Note the stairs, which also could be termed ladders. Such marine stairways probably were what Verne had in mind for the central stair or “ladder” of his *Nautilus*. Submariners know the hand rails on the ladder should extend nearly to the deck, to aid fast descents by sliding. (*London Illustrated News*,)

There is no original illustration in the novel showing the engines of Verne's *Nautilus*, but the view above of the steam engines of the *Great Eastern* shows the character of engines of the time, and these are marine engines in an engine room which Verne saw when he was first planning the novel.

An Assessment of Jules Verne's Submarine *Nautilus*

For a novelist Verne presents technical matters in an unusually detailed manner. He was not an engineer, but he did recognize several important factors of submarine design, combined the latest marine technology of his day with projections of plausible future developments, and conceived and described in detail a submarine which was remarkably foresightful. Verne is not counted among the "serious" novelists by the *litterateurs*, but he is a leader among those rare and remarkable persons who foresaw actual and hugely-important transformations in technology and society long before they occurred.

The close fit of the *Nautilus*'s hull shape with its interior layout, and how all the compartments fit together consistently, suggests to me that Verne created actual drawings to guide his thinking and descriptions. It is unlikely that the various numerical dimensions of the *Nautilus*, internal and external, carefully given by Verne, would agree this way if his creation were entirely verbal, written with no reference to a scaled drawing. Verne's submarine *Nautilus* is much more than a fantasy of a novelist's imagination, and more like a preliminary sketch of an actual design.

Some technical points may be made about Verne's submarine in *Twenty Thousand Leagues Under the Seas*. Verne showed great foresight about how technology of his day signaled possibilities about the future; his submarine description is self-consistent and detailed enough to permit drawings to be made and judgments to be passed about its design as if for a preliminary design for a real ship; and the design incorporates important features used by actual submarine builders.

This section discusses his design, and how to fix its problems while retaining as much of his concept as possible. As a thought experiment let us improve Verne's design, on step at a time, in light of later experience, to create a submarine with the best possible performance while keeping as much of his *Nautilus* as possible.

First it is important to say that Verne's *Nautilus* is carefully detailed and it could be built pretty much as he described – under the limitation that the batteries and engine he described did not yet exist. If we used the best modern (powerful) electrical motor and the best modern (but fairly limited) batteries, the performance would still fall far short of the performance described by Verne. The batteries would provide power only for a few hours of operation at low speeds. Verne's proposed sodium-zinc battery elements would have to be dispensed with, since they might cause toxic fumes, fire, or explosions the moment they came in contact with the battery fluid.

The hull shape described by Verne and shown in the illustrations is a reasonable one for submerged operations. In fact Verne's *Nautilus* in shape and size is perfectly acceptable. Dock Verne's *Nautilus* at a submarine base today and it would not attract much notice or comment, except for the lack of a sail or conning tower. Perhaps a new experimental boat with a retractable sail? I am assuming the hull actually is smooth, with no overlapping plates or lines of rivets. The hull flattened on top into a deck is quite ordinary. The sharply-pointed bow is not the best design practice now, but that would not make a vital difference in performance.

Similar submarine hulls with cylindrical central sections, rounded bows, tapering sterns, and few angles or protrusions are in widespread use today, as in the US *Los Angeles* class. This shape is fine for submerged running but poor on the surface. Surfaced, waves easily pass over the bow. With a freeboard less than a meter, Verne's deck platform would frequently be swept by waves except in the calmest conditions, as in sheltered harbors. Underway with any waves or at any speed, the low pilot house would be smothered in waves and foam, rendering the windows of little value for the helmsman. Open hatches for ventilation which Nemo describes would ship tons of water. The image of the *Nautilus* surfaced and cruising the open Pacific Ocean with crew members strolling on deck is wholly unrealistic. This same problem plagued early 19^{th} century submarines with similar hull shapes, the solution being conning towers for all boats, and surface-ship-like upper hull work for vessels operating routinely on the surface, the case before atomic power. Since the *Nautilus* usually operates submerged, like modern nuclear submarines, we can retain Verne's hull form, and even keep the pilot house. Of course visual steering will have limited use submerged as well as surfaced, so proper navigation and sonar instruments are also needed.

The hull construction requires attention. The enormous depth capability of Verne's *Nautilus* is impossible, as for for any modern submarine this size. The maximum depth of Verne's proposed construction would be hundreds of feet, not thousands of meters, and the hull made of riveted plates is a leak prone design. But if we accept a 5 cm thick (2 inches) welded steel hull of the same shape, much like modern pressure hulls, a maximum depth of perhaps 300 meters (1000 feet) could be possible. Alternatively, the exterior shape of the *Nautilus* could be retained while using an inner pressure hull with a lighter outer hull. Some hull design improvements are required, but they need not be too far from Verne's suggested "cellular" double hull.

Verne provides for vertical control with one pair of diving planes at the center of flotation. His idea, shared by builders of actual submarines of his time, seems to be that inclining the planes slightly would cause a neutrally-buoyant vessel to dive or rise on an even keel. In fact diving planes at the center of flotation are basically useless. Many factors can cause a submarine to pitch up or down, and central diving planes are in the worst position to counter such motions. Two pairs of diving planes are the common solution, one near the stern and the other pair forward of center. The long moments of action provided by the separation of these control surfaces laterally from the center of flotation allow positive control of pitch. Let's say we add diving planes at the stern, and keep the pair of central planes, or move those forward, and let's combine steering and dive controls into a single yoke with computer-controlled, hydraulic-assisted action in place of a the large ship's wheel, and you could maneuver the *Nautilus* something like an airplane.

Verne calls for ballast tanks of some 150 cubic meters capacity in the lower part of the hull. There is nothing particularly wrong here, but larger tanks are better and various auxiliary and trim tanks are needed, also. His use of pumps to empty the tanks – inside the pressure hull – causes all kinds of problems. Such tanks and pumps would have to be as pressure-resistant as the pressure hull, for example. It is better to use compressed air than water pumps, and ballast tanks outside the pressure hull.

Based on Verne's description of the internal furnishings, there is a shortage of weight to come up to the 2500 ton displacement, and the center of mass seems to be aft of center. A design problem here, but not impossible to correct.

The lack of an adequate power supply is the outstanding deficiency of Verne's design, as it was for all submarines until the close of the 19^{th} century. Seeking to base his submarine on known technology, Verne suggested electrical batteries for power, admittedly batteries far more powerful than any in his day. Even today batteries are used for supplemental submarine power, but for propulsion they only last hours, not the weeks and months desired for Verne's *Nautilus*. Only a nuclear reactor can provide power for submarines to operate for months, free of the need for air for engines, and free of the need for frequent refueling; only a nuclear reactor can provide the high power necessary for Verne's *Nautilus* to achieve its speeds.

The power required to attain the speeds given for the *Nautilus* can be estimated from performance of similar submarines and basic scaling laws such as the shaft horse power required for a given speed being approximately proportional to the cube of of the speed. I estimate, very approximately, the shaft horse power (shp) for Verne's

Nautilus at 3,300 shp for 20 knots, 7,000 shp for 25 knots, 12,000 shp at 30 knots, 16,500 shp for 35 knots, and more than 27,000 shp for 40 knots, submerged speeds. How powerful a reactor and engine combination could fit in the engine room in Verne's *Nautilus* is more than I can say, but perhaps less than 5,000 or 10,000 horsepower.

With some modifications, which do not require large changes in *appearance*, a workable version of Verne's *Nautilus* could be built today. It would require nuclear power, better hull construction, changes in diving planes and controls, and considerable attention to ballast and other matters. A modern propeller would increase speed and range. Whether it would have a library of 12,000 volumes, or a grand salon with fine art by old masters, is up to the owner to decide. It would cost a fortune to build – but the art and furnishings might cost more, as it did in Verne's day.

Verne's submarine design is centered around the large salon, the library, living quarters, and the dining room, with a generous space for the engines. Modern naval submarines appear to be designed around the power plant, engines and weapons, and they are subject to operational requirements such as a draft small enough to navigate shallow passages. Human activities are tucked into spaces among the machinery. Verne's *Nautilus* is for humans investigating the sea, and making their home at sea.

March 9, 2015.

Appendix A: Numerical details

Units of Measure

In Jules Verne's *Twenty Thousand Leagues Under the Seas*, short lengths are measured in meters, the modern meter (3.28 feet). Verne also uses the French *pied* or foot whose exact value in modern terms I do not know, but it may be close to, but differ from, the English foot (0.305 m).

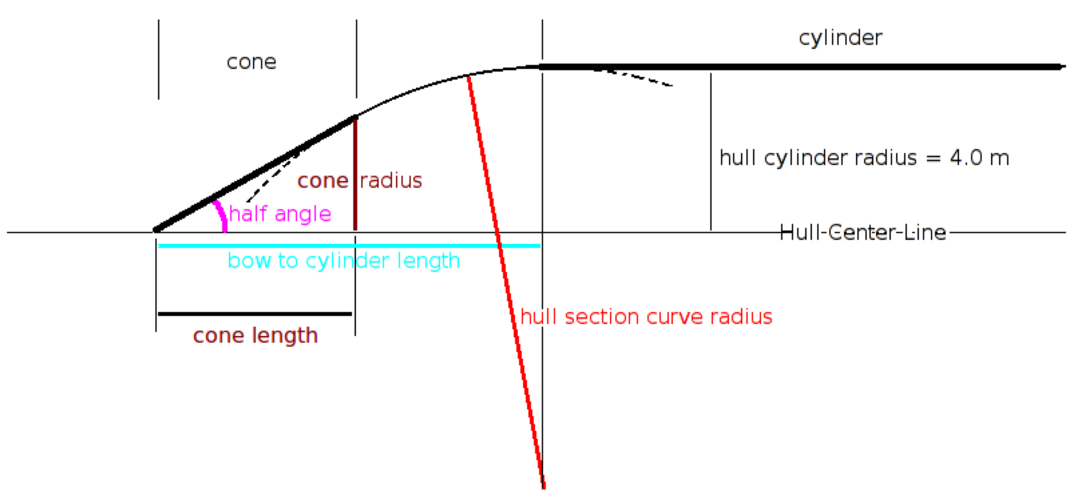
Verne's league, *lieue*, is 4000 kilometers long (2.5 English statute, land, miles): "Nous avions atteint une profondeur de seize mille mètres — quatre lieues...." (We have attained a depth of 16000 meters – four leagues). The twenty thousand leagues of the title is 80,000 kilometers or 50,000 miles. That is how far the *Nautilus* traveled during the course of the novel.

Speeds are given as *milles à l'heure*, French miles per hour, not as you might expect in kilometers per hour. The unit kilometer does not appear (to me at least) to be used even once in the novel. French *milles*, miles, can refer either to French statute miles or to nautical miles, so speeds in the novel may be intended to be either French miles per hour or nautical miles per hour. The exact value of the French non-nautical *mille* in 1870 is unknown to me. The nautical mile is universal, the same for all seamen, being one arc minute or one sixtieth of the length of a degree of latitude, in other words determined by the size of the Earth, and is 1.83 km. A nautical mile per hour, or knot, is 1.83 kilometers per hour or 1.15 English miles per hour.

Tons in this report refers to the metric ton or tonne, the weight of a cubic meter of pure water, 1000 kg or 2204 pounds, and presumably is what Verne had in mind. This is quite close to the "long ton," of 2240 pounds, used in the U.S. for ship displacements.

Hull Cross-sections

As described in the text a true cone at each end of the hull can be smoothly joined to a central cylinder, by means of a curving shape, the cylinder-to-cone transition junction. The curve on an along-axis vertical cross section is most simply a circular arc. For any length of the purely conical ends the hull, the radius of a circular arc can be exactly calculated to join it with the center cylindrical section of the hull. The calculation also gives the required base diameter of the cone. So for any given cone length, or any bow angle, you can calculate a unique cone base diameter and the arc radius to merge the cone with any given diameter cylinder. Here are a diagram



and some examples of values of the parameters. (The case of simple conical ends on a cylinder, with no curved transition region at all, is a limiting case of this method of calculation, where the curved transition section has zero length.)

The hull shape shown in the plans of Verne's *Nautilus* prepared for this report (Figure 1) has a length of the true conical ends of 5 meters (16.4 feet), a cone base diameter of 3.24 meters (10.6 feet), and the central cylindrical section of the hull is 30 meters (98.4 feet) long. The connecting arc (cylinder-to-cone transition junction) has a radius of 48.5 m (159 ft) in this case. This arc radius would be used in drafting the hull design. The tapering parts of the hull at each end, including cone and junction, are 20 meters long (65.6 feet).

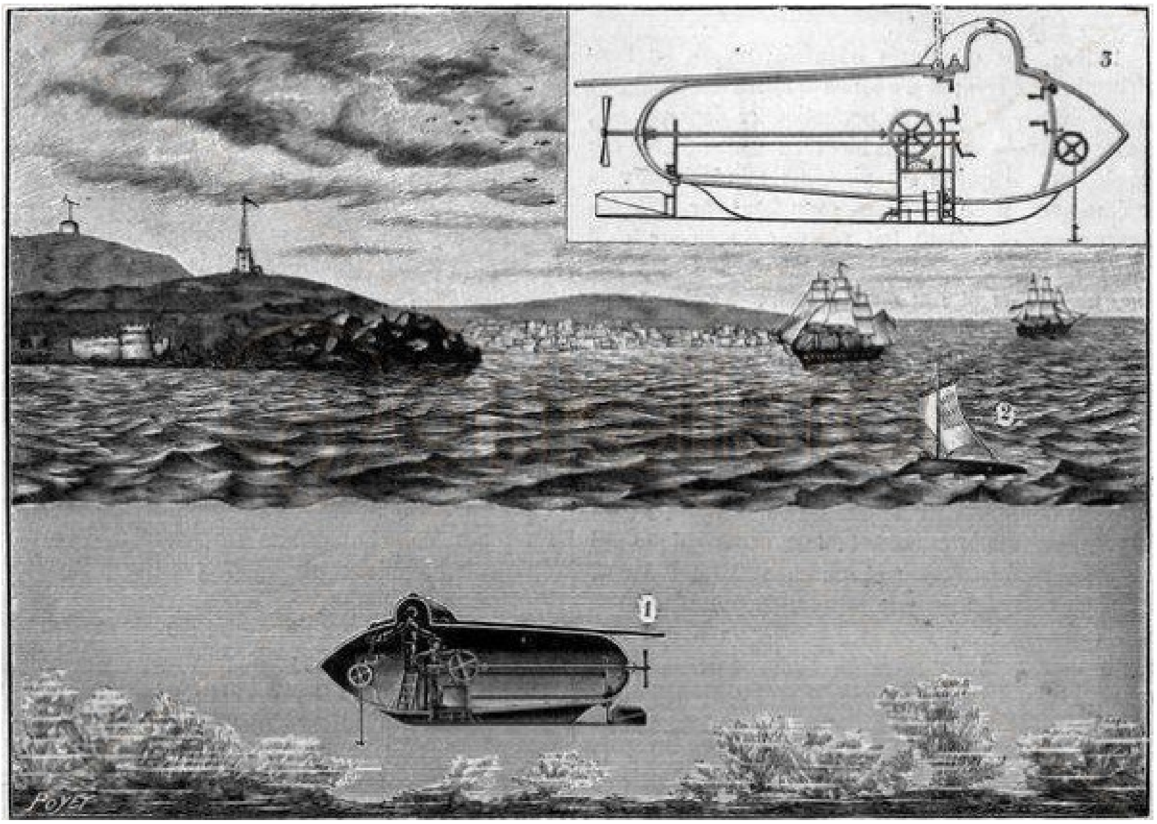
Here are some examples of combinations of conical end sections and circular arcs for the cylinder-to-cone transition junction, with a central cylindrical section of 8 meters diameter.

end cone length	half angle	cone base radius	junction curve radius	end point to cylinder length (taper)
2.0 m	.0 deg.	m	m	m
2.5 m	.0 deg.	m	m	m
3.0 m	38.0 deg.	2.34 m	7.81 m	11.03 m
4.0 m	26.0 deg.	1.95 m	20.25 m	14.11 m
5.0 m	**18.0 deg.**	**1.62 m**	**48.53 m**	**20.00 m**
6.0 m	18.0 deg.	1.95 m	41.89 m	17.84 m
7.0 m	20.0 deg.	2.55 m	24.08 m	12.97 m

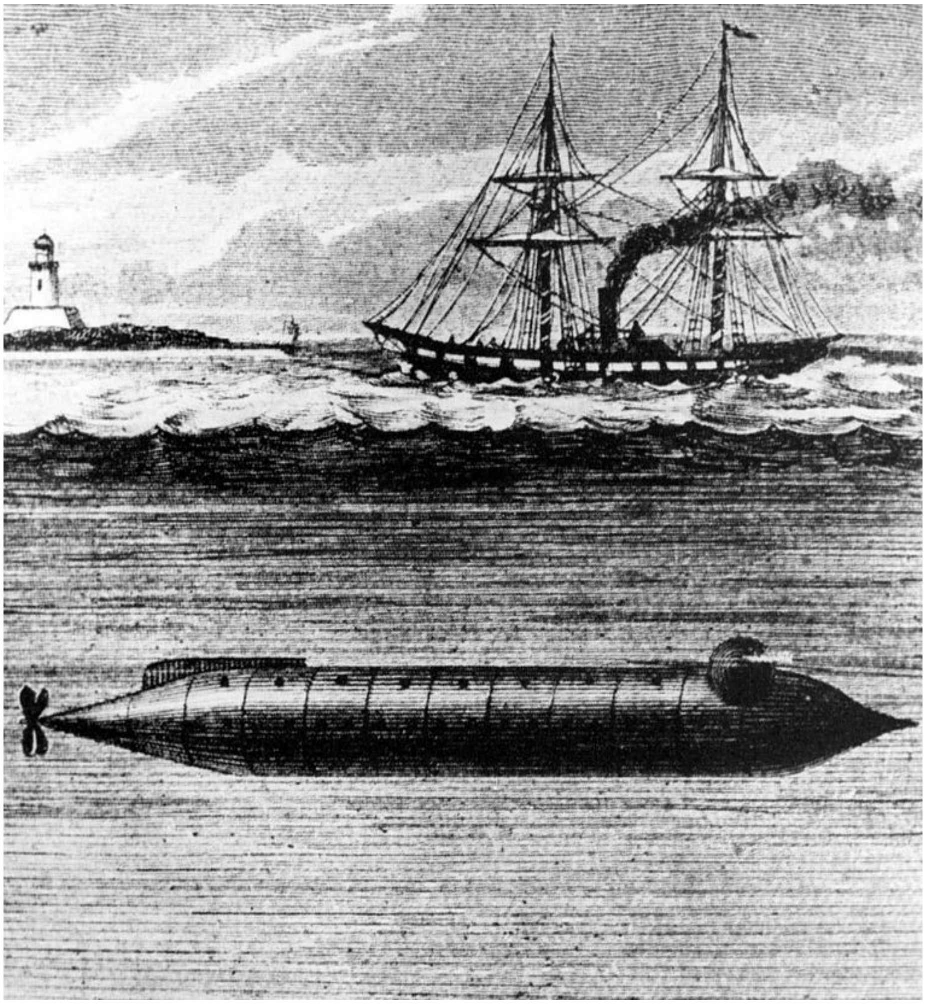
To include the height and width of the foward end of the salon inside the hull, hulls with more than 20 meters length in the cone plus transition junction are too streamlined. So the two end cones' lengths must be no more than 5 meters each. The hull need not be more blunt than that, with cone lengths less than 5 m

Appendix B: Submarines Built Before Verne’s *Nautilus*

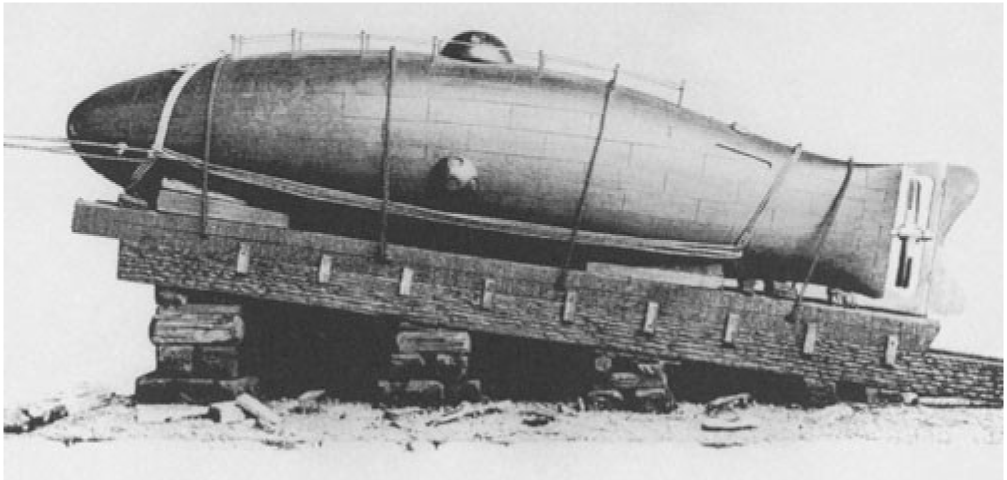
Here are views of actual submarines built before Verne wrote *Twenty Thousand Leagues Under the Seas.* These have some features similar to parts of Verne's *Nautilus*, such as hull forms, rudders, propellers, and pilot houses. How much Verne knew of any of these, or was influenced by them, is a good topic for another investigation.



Robert Fulton's *Nautilus* (1793-1801), built in France, was a proven success in several trials. With a helmsman and two crew turning the propeller it could dive to 7 meters (23 feet) and remain submerged for more than an hour. Length 6.5 meters (21.2 feet), beam 1.9 meters (6.3 feet). Towing a mine, it could destroy a conventional wooden ship without being detected. A French government committee proposed plans for a larger version, but it did not earn the approval of the French navy despite their ongoing war with England. Perhaps they were rightly worried about their own ships, if the English copied the idea. Fulton then moved to England, where he prposed the idea to the British navy, and was turned down again. Probably the British naval officers preferred to win the generous prize money awarded for captured ships, rather than sink them. (19th-century illustration).



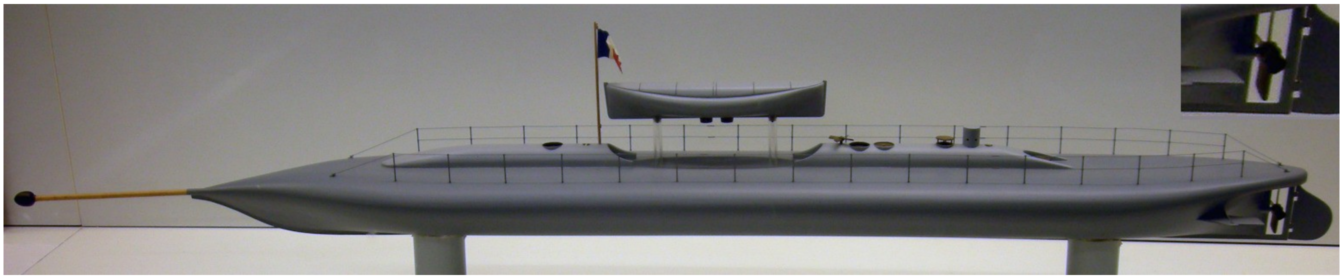
Artist's conception of Brutus de Villeroi's *Alligator*, United States, 1862, about which little is known. The actual vessel did have a rudder, not shown here. Length estimated to be 30 to 46 feet, and diameter of 5 to 8 feet. Compare to Verne's novel's illustration of the *Nautilus* passing a sinking ship. (Photo from NavSource Online: Submarine Photo Archive, http://www.navsource.org/archives/08/08444.htm, accessed Feb 3, 2013)



Narcis Monturiol Estarriol's *Ictineo I,* Spain. (period illustration)

"Built in 1859, it was the first submarine able to routinely dive to a depth of 20 meters and navigate there under the hand-power of a crew of up to six men. Its inventor, the idealistic visionary Narcís Monturiol, conceived of it as a 'new fish'—hence the name Ictíneo*."* – Matthew Stewart, in *Monturiol's Dream: The Extraordinary Story of the Submarine Inventor Who Wanted to Save the World,* Pantheon, 2003. Several close parallels Verne's design for the *Nautilus* are clear.

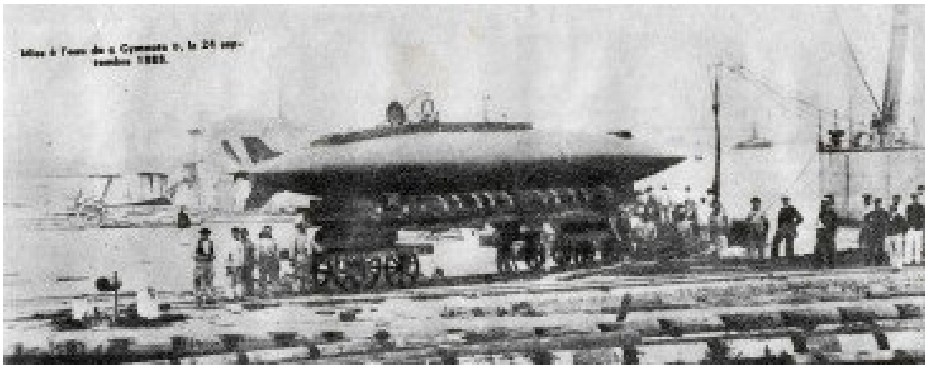
Replica of Narcis Monturiol Estarriol's *Ictineo II*, 1865-1867.
Length 14 meters (46 feet), beam 2 meters (6.5 feet). (photo by Flemming Mahler Larsen, from Wikipedia)



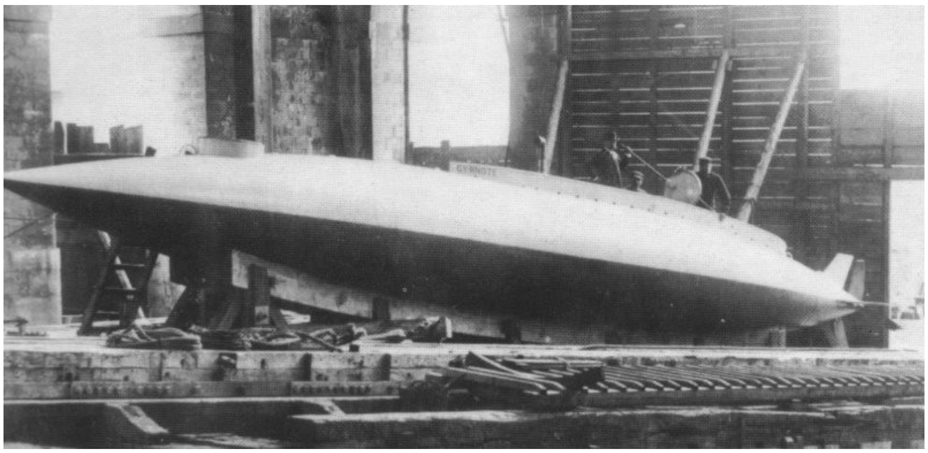
Captain Siméon Bourgeois' *Plongeur*, France, 1863 - 1872. Length 43 meters (141 feet); displacement 380 tons. Note the large ship's boat and a recess for the boat in the deck, a single four bladed propeller, and the rudder aft of a sternpost, all features which Verne also used for his *Nautilus*. *Plongeur* was the world's first submarine propelled by mechanical rather than human power, using an 80 horsepower engine powered by compressed air. In several ways the *Plongeur* was clearly the most advanced submarine built preceding Verne's novel. Model in the Munich Science Museum. Photography by Lamgi-Mari, 2010, from Wikipedia.

Appendix C: Submarines Built after Verne's Novel

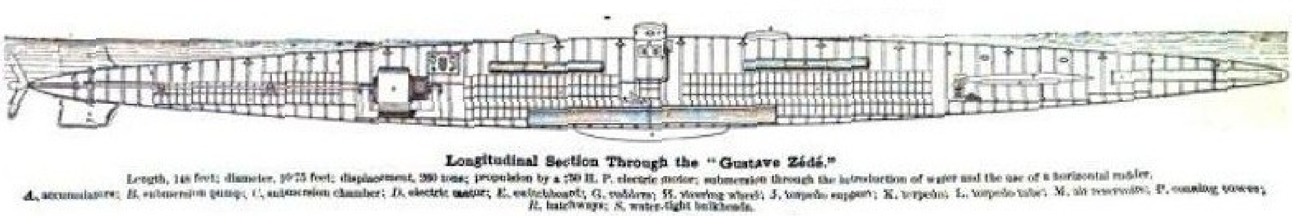
Isaac Peral y Caballero's *Peral,* 1888, length 22 m (72 feet).

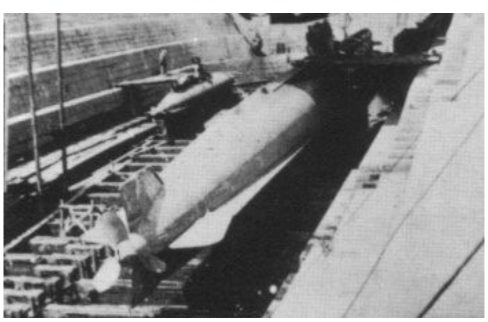


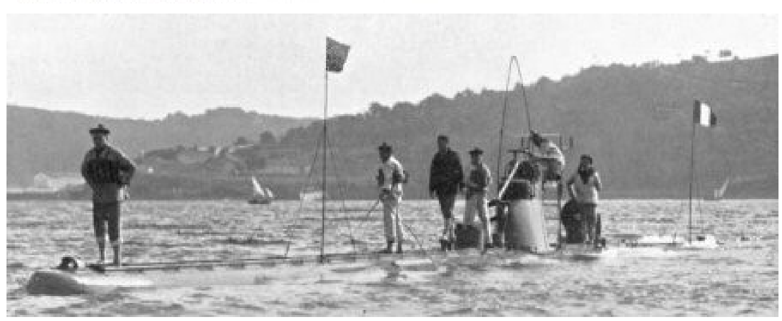
Gustave Zede's *Gymnote*, launching, 1888. Length 17.8 m (58.4 ft).



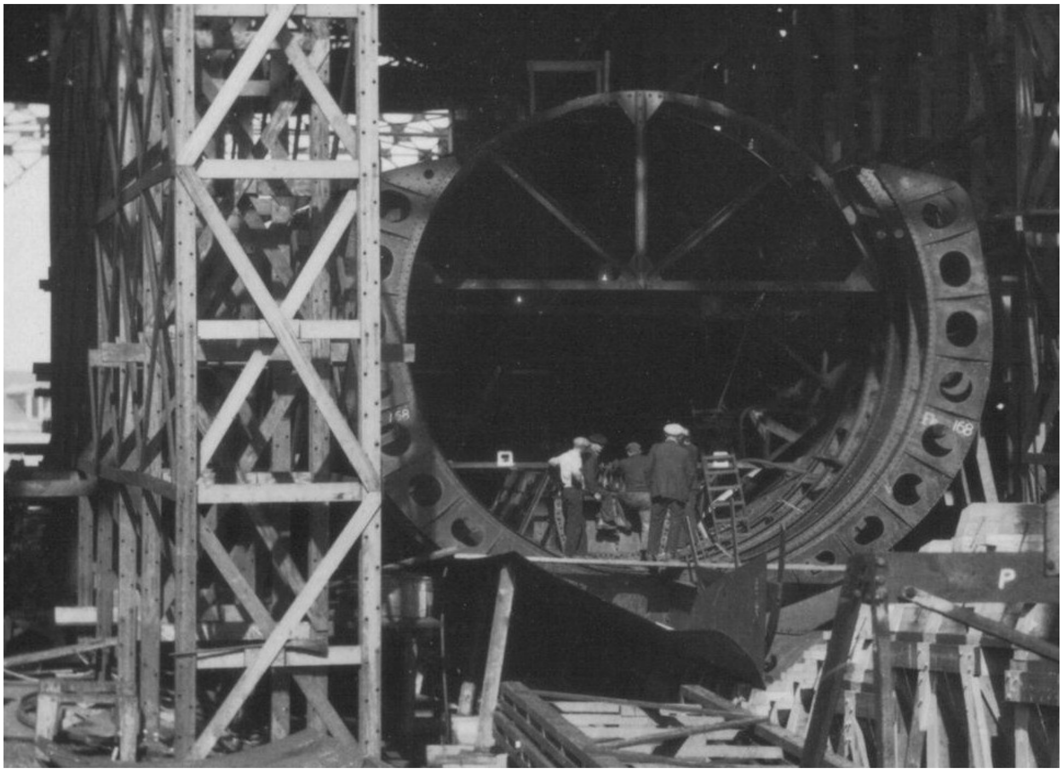
Gustave Zede's *Gymnote*, 1889.



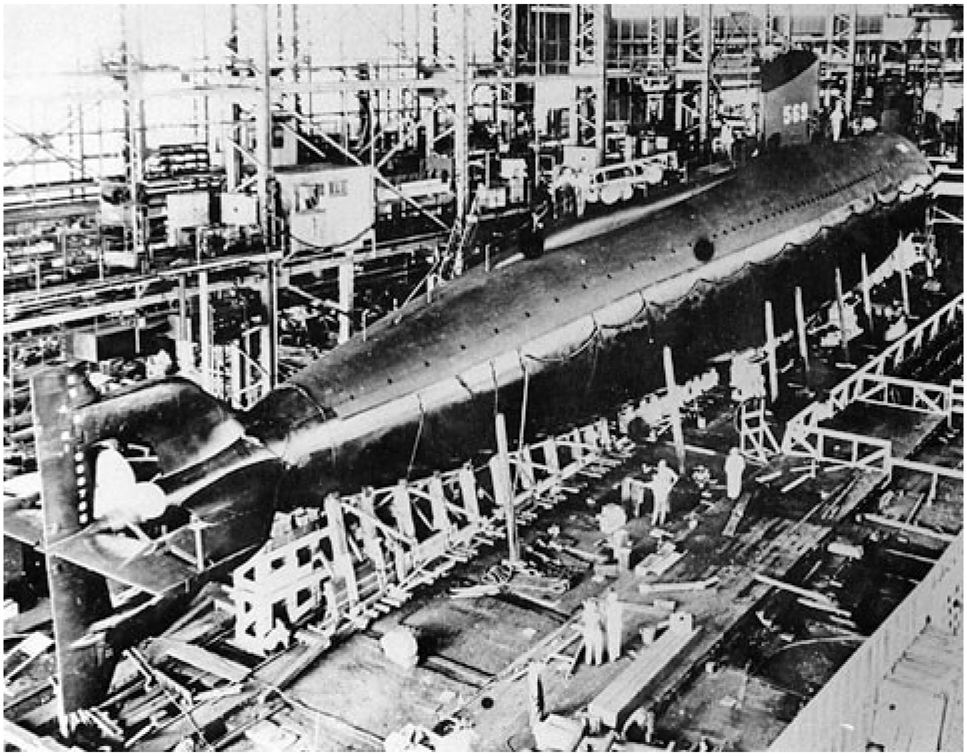




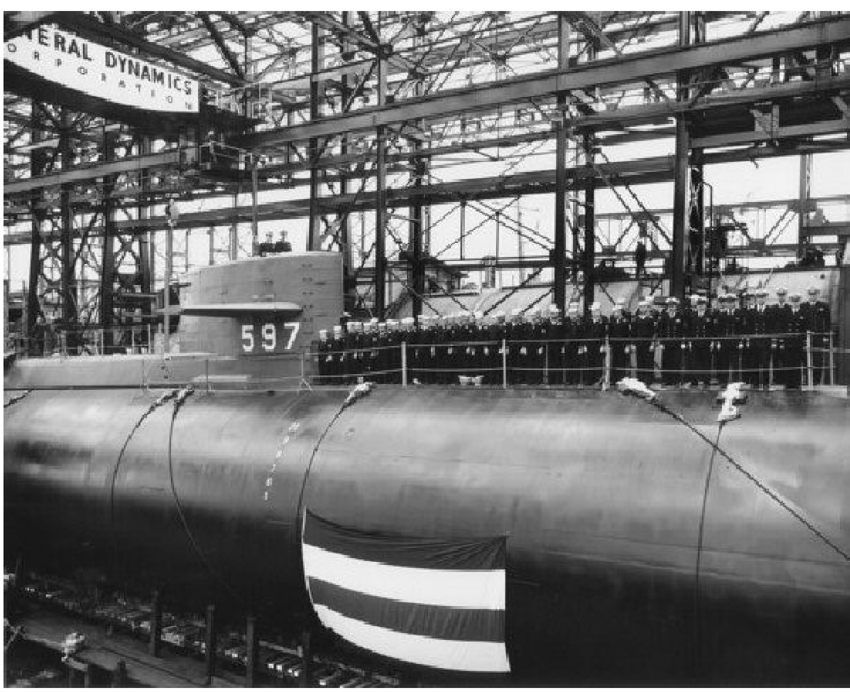
"Gustave Zédé," 1898. Length 148 feet. (plan from *Scientific American*, 1903)
262 tons surfaced; 270 tons submerged. Crew 19. Top speed: 9 knots surfaced and 6.5 knots submerged.
Range: 105 nm at 4.5 knots submerged. Note the *very* marginal freeboard when surfaced.



Here is the USS *Narwhal* (V-5, later SS-167) under construction in 1927. The *Narwhal* had a circular cross-section and a double hull, similar to the hull design which Verne described for his *Nautilus*. The beam (diameter) of this hull is 10.14 m (33.3 feet), compared to the 8 m (26.3 feet) of the *Nautilus*. The 27% increase in beam provides about 60% more interior volume per unit length. The *Narwhal* was considerably larger than Verne's *Nautilus*, and larger than other US subs until late 1960s nuclear ships. Submerged displacement 3900 short tons. This photo has a feeling something like Verne's *Nautilus* under construction, were that possible.
U.S. Navy photograph.

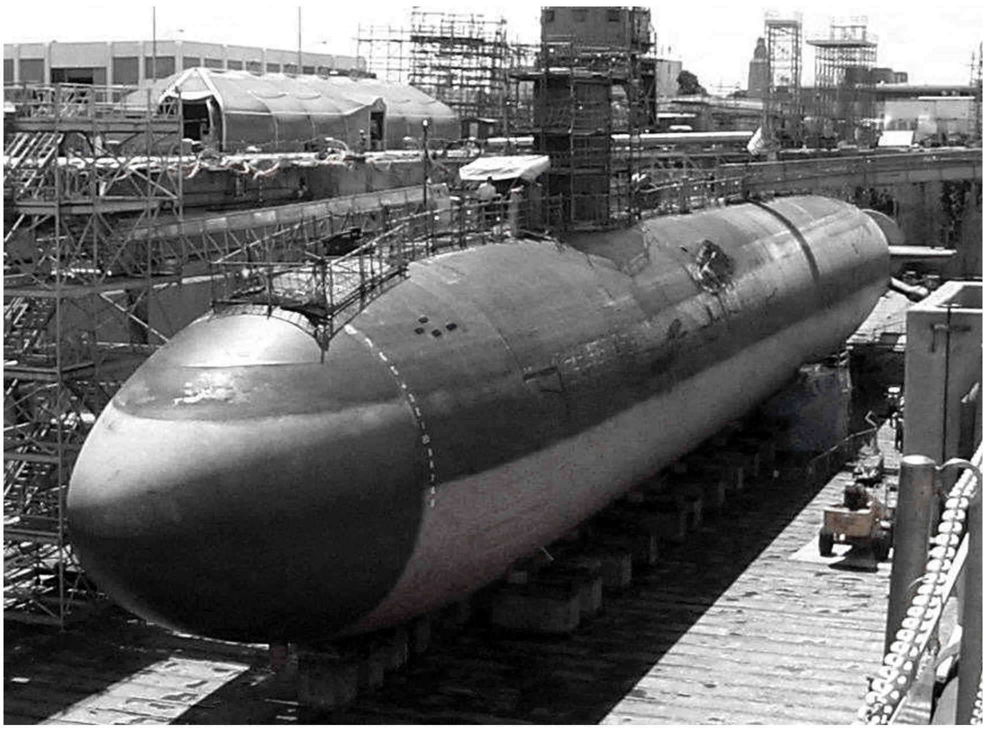


USS *Albacore*, in construction, 1953. A modern experimental sub, designed for high performance, and similar to Verne's *Nautilus* in size, shape, and having circular sections throughout and a long tapering stern. Note layout of propeller and rudder at the stern, mounted on a “sternpost,” to use Verne's term. The length is 205 feet (62.5 m), beam 27 feet (8.25 m), that is, 7.5 meters (25 feet) shorter and 0.25 meters (10 inches) wider than Verne's *Nautilus*. Complement 5 officers and 50 enlisted men. Submerged speed 35 knots, and possibly more. The *Albacore* was designed to have the most low-drag hull shape possible, and is not cylindrical in the middle as was Verne's *Nautilus*. U.S. Navy photograph.



The US submarine closest in shape and size to Verne's *Nautilus* was the *Tullibee,* SSN-597 (1960-1987), shown here during launching. Length 273 feet (83 m), beam 23' 7" (7.19 m) displacement 2316/ 2607 tons, complement 66, atomic power (S2C reactor). 13 knots surfaced; 15 knots submerged. The *Tullibee* was like Verne's *Nautilus* in having circular sections, a cylindrical mid section, and a single axial propeller. It was 13 m (43 ft) longer and had 0.8 m (2.7 ft) smaller beam. This photograph indicates the size of crewmen compared to the *Tullibee* - and to the *Nautilus*. U.S. Navy photograph.

The *Tullibee* underway on the surface. The *Tullibee* was close to the shape and size of Jules Verne's *Nautilus*, with a cylindrical mid-section and a flattened hull for an upper deck or platform. The *Nautilus* lacked the large structures above the hull seen here on the *Tullibee*, instead having a small pilothouse, about 1.5 m (5 feet) high, near the location of the forward vertical fin of the *Tullibee*. Note the freeboard of the *Tullibee*, 2 m (6 feet) or more, is much larger than the 0.8 meter (31 inches) freeboard of the *Nautilus*. The *Nautilus* would not emerge even half this much above the surface, and its deck could easily be swept by waves. U.S. Navy photograph.



USS *Greeneville* (SSN 772), in dry dock in 2001. Like Jules Verne's *Nautilus*, the US *Los Angeles* class submarines, built from 1972 to 1996, have a long central cylindrical hull segment with modest flattening on top to provide an exterior deck, circular cross sections, tapering bow and stern, and a single axial propeller. The point of the bow is rounded for reduced water drag, compared to the conical point of the *Nautilus*, but otherwise the tapering forward hull curves are similar. The *Nautilus* lacked the large sail. The *Los Angeles* class submarines' hulls are 57% longer and 25% wider than the *Nautilus*, with 2.8 times the displacement. Power is about 35,000 horsepower giving perhaps 25 knots to 37 knots submerged (46 to 68 km/hr).   U.S. Navy photograph.

Appendix D: Original text describing technical details

This section shows selections from Verne's novel which bear on the design and operation of the submarine. Translations and interpretations are by the author. Note that nautical terminology is not usually available in common French-English dictionaries. I used a French dictionary of 1907 to help avoid more recent definitions for technical terms and other words. My translations simplify some of the ornate French of Verne, a 19th century novelist, but strive to make technical details as clear and as correct as possible. More translations may be added.

The Hull:

“The enormous cylinder of sheet iron” from “L'énorme cylindre de tôle” "Tôle" alone means sheet metal or sheet iron; elsewhere Verne says "tôle d'acier,” sheet steel.

“was smooth, polished, and not imbricated” from “était lisse, poli, non imbriqué.”

“made of bolted plates.” “il semblait que, dis-je, il était fait de plaques boulonnées.”

“the iron plates, lighty imbricated, resembled the shells of large terrestrial reptiles.“ “Je remarquai que ses plaques de tôles, imbriquées légèrement, ressemblaient aux écailles qui revêtent le corps des grands reptiles terrestres. “

“elongated cylinder, with conical ends” “C’est un cylindre très allongé, à bouts coniques. "

“has the shape of a cigar” “affecte sensiblement la forme d’un cigare”

“the bow and stern of the *Nautilus* are spindle shaped, like a long cigar” “L’avant et l’arrière du *Nautilus* présentaient cette disposition fusiforme qui le faisait justement comparer à un long cigare.”

“the length of the cylinder from end to end is exactly 70 meters” “La longueur de ce cylindre, de tête en tête, est exactement de soixante-dix mètres”

“maximum beam is eight meters” “on bau, à sa plus grande largeur, est de huit mètres”

““its lines are sufficiently long and its streamlines prolonged enough, that displaced water moves aside easily and opposes no obstacle to its progress.” -- This is a tricky one: “ses lignes sont suffisamment longues et sa coulée assez prolongée, pour que l’eau déplacée s’échappe aisément et n’oppose aucun obstacle a sa marche.”

“a hole like isosceles triangle 2 meters across, as if made by a cutting machine.” from “un trou large de deux mètres dans la carène du steamer … une déchirure régulière, en forme de triangle isocèle. La cassure de la tôle était d’une netteté parfaite, et elle n’eût pas été frappée plus sûrement à l’emporte-pièce. Il fallait donc que l’outil perforant qui l’avait produite fût d’une trempe peu commune.”

“when floating it emerges from the water only one tenth, so it must displace in those conditions no other than nine tenths of its volume.“ from “qu’en équilibre dans l’eau il plongeât des neuf dixièmes, et qu’il émergeât d’un dixième seulement. Par conséquent, il ne devait déplacer dans ces conditions que les neuf dixièmes de son volume“

“made with two hulls, one inside the other...joined by T-shaped irons which gives extreme regidity: ” “Le *Nautilus* se compose de deux coques, l’une intérieure, l’autre extérieure, réunies entre elles par des fers en T qui lui donnent une rigidité extrême. “

“cellular hull structure” and “it resists the pressure of the depths like a solid block. Its boundary cannot yield.” "En effet, grâce à cette disposition cellulaire, il résiste comme un bloc, comme s’il était plein. Son bordé ne peut céder...“

“The two hulls are built of sheet steel (density 7.8 gm/cm^3). The outer hull is no less than 5 centimeters (2.0 inches) in thickness. “ “Ces deux coques sont fabriquées en tôle d’acier dont la densité par rapport à l’eau est de sept, huit dixièmes. La première n’a pas moins de cinq centimètres d’épaisseur...”

“The keel is 50 cm (20 inches) high and 25 centimeters (10 inches) thick.“ “la quille, haute de cinquante centimètres et large de vingt-cinq”

“we reached a depth of 1600 meters -- four leagues ...” – “Nous avions atteint une profondeur de seize mille mètres — quatre lieues — et les flancs du *Nautilus* supportaient alors une pression de seize cents atmosphères, c’est-à-dire seize cents kilogrammes par chaque centimètre carré de sa surface ! “

Displacement of “1500.2 cubic meters, that means when entirely submerged it displaces or weighs 1500 cubic meters or tons”, from:

“Ces deux dimensions vous permettent d’obtenir par un simple calcul la surface et le volume du *Nautilus*. Sa surface comprend mille onze mètres carrés et quarante-cinq centièmes; son volume, quinze cents mètres cubes et deux dixièmes - ce qui revient à dire qu’entièrement immergé, il déplace ou pèse quinze cents mètres cubes ou tonneaux. “

“I wished, when floating in the water it would drawn nine tenths and that it would emerge only one tenth. Consequently in these conditions it must displace nine tenths of its volume, 1356.48 cubic meters.” - “ j’ai voulu, qu’en équilibre dans l’eau il plongeât des neuf dixièmes, et qu’il émergeât d’un dixième seulement. Par conséquent, il ne devait déplacer dans ces conditions que les neuf dixièmes de son volume, soit treize cent cinquante-six mètres cubes et quarante-huit centièmes...”

The Platform:

“the hull which forms at its upper part a sort of horizontal platform” “la coque qui formait à sa partie supérieure une sorte de plate-forme horizontale”

“the plaform rises above the level of the sea only some 80 centimeters (31 inches)” “La plate-forme émergeait de quatre-vingts centimètres seulement.”

About the ship's boat:

There is a dinghy, "light and unsinkable, for excursions and fishing": “légère et insubmersible, qui sert à la promenade et à la pêche. “

"I followed Captain Nemo across the internal passageways and arrived at the center of the ship. There was located a sort of well opening between two watertight partitions. An iron ladder attached to the side led to its upper extremity [of the well]. I asked the captain the use of this ladder. It leads to the dinghy, he replied." :

"Je suivis le capitaine Nemo, à travers les coursives situées en abord, et j'arrivai au centre du navire. Là, se trouvait une sorte de puits qui s'ouvrait entre deux cloisons étanches. Une échelle de fer, cramponnée à la paroi, conduisait à son extrémité supérieure. Je demandai au capitaine à quel usage servait cette échelle. Elle aboutit au canot, répondit-il."

"Near the middle of the deck the dinghy, half embedded in the ship's hull, formed a slight bulge": "Vers le milieu de la plate-forme, le canot, à demi-engagé dans la coque du navire, formait une légère extumescence."

"the dinghy, uncovered, was drawn up out of its recess and launched in the sea from the height of the platform. Two men sufficed for this operation. Two men were sufficient for this operation. The oars were in the boat." : "le canot, déponté, fut arraché de son alvéole et lancé à la mer du haut de la plate-forme. Deux hommes suffirent à cette opération. Les avirons étaient dans l'embarcation..."

"seated on the protrusion made by the hull of the dinghy, I breathed with delight the salt air.": "Assis sur la saillie produite par la coque du canot, j'aspirai avec délices les émanations salines."

"...entirely decked over, absolutely watertight, and held in place by solid bolts. This ladder leads to a hatch in the hull of the *Nautilus*, which corresponds to similar hatch pierced in the side of the dinghy. This double opening admits me to the boat. Someone closes the hatch of the *Nautilus*, and I close the other in the dinghy, by means of force of pressure. I release the bolts and the boat rises with tremendous speed to the surface of the sea. Then I open the panel of the deck, carefully closed until then, I step the mast, I raise sail or take my oars, and go on my way." :

"Ce canot adhère à la partie supérieure de la coque du *Nautilus*, et occupe une cavité disposée pour le recevoir. Il est entièrement ponté, absolument étanche, et retenu par de solides boulons. Cette échelle conduit à un trou d'homme percé dans la coque du *Nautilus*, qui correspond à un trou pareil percé dans le flanc du canot. C'est par cette double ouverture que je m'introduis dans l'embarcation. On referme l'une, celle du *Nautilus* ; je referme l'autre, celle du canot, au moyen de vis de pression ; je largue les boulons, et l'embarcation remonte avec une prodigieuse rapidité à la surface de la mer. J'ouvre alors le panneau du pont, soigneusement clos jusque-là, je mâte, je hisse ma voile ou je prends mes avirons, et je me promène. "

ten men in dinghy - "Six oarsmen took places on their thwarts and the master placed himself at the tiller. Ned, Conseil and I took the stern." "Six rameurs prirent place sur leurs bancs et le patron se mit à la barre. Ned, Conseil et moi, nous nous assîmes à l'arrière."

"all the forward part of the submarine": "toute la partie antérieure de ce bateau sous-marin"

Après avoir dépassé la cage de l'escalier qui aboutissait à la plate-forme, je vis une cabine longue de deux mètres, dans laquelle Conseil et Ned Land, enchantés de leur repas, s'occupaient à le dévorer à belles dents. Puis, une porte s'ouvrit sur la cuisine longue de trois mètres, située entre les vastes cambuses du bord.

the windows ..." - "Soudain, le jour se fit de chaque côté du salon, à travers deux ouvertures oblongues. "

the main staircase... - "la cage de l'escalier qui aboutissait à la plate-forme,

a cabin 2 meters long (6.56 feet, along the the axis of the submarine) occupied by Conseil and New Land, and then the galley 3 meters (9.8 feet) long, placed between large storerooms. - "je vis une cabine longue de deux mètres, dans laquelle Conseil et Ned Land, enchantés de leur repas, s'occupaient à le dévorer à belles dents. Puis, une porte s'ouvrit sur la cuisine longue de trois mètres, située entre les vastes cambuses du bord."

the crews' quarters, 5 meters (16.4 feet) long, but the door was closed and he could not see its arrangement. - "A la cuisine succédait le poste de l'équipage, long de cinq mètres. Mais la porte en était fermée, et je ne pus voir son aménagement"

the compartment where Aronnax, Conceil and Ned Land were detained, 20 feet (French *pieds*) long and 10 feet wide- "cette cabine, qui devait avoir vingt pieds de long sur dix pieds de large."

behind a watertight bulkhead is the engine room, 20 meters (65.6 feet) long - "Au fond s'élevait une quatrième cloison étanche qui séparait ce poste de la chambre des machines. … Cette chambre des machines, nettement éclairée, ne mesurait pas moins de vingt mètres en longueur."

"the dynamic power of my engines is nearly infinite" : "le pouvoir dynamique de mes machines est à peu près infini."

Batteries, propeller, and engines - "J'emploie des éléments Bunzen, et non des éléments Ruhmkorff. Ceux-ci eussent été impuissants. Les éléments Bunzen sont peu nombreux, mais forts et grands, ce qui vaut mieux, expérience faite. L'électricité produite se rend à l'arrière, où elle agit par des électro-aimants de glande [?] dimension sur un système particulier de leviers et d'engrenages qui transmettent le mouvement à l'arbre de l'hélice. Celle-ci. dont le diamètre est de six mètres et le pas de sept mètres cinquante, peut donner jusqu'à cent vingt tours par seconde."

sodium element for the batteries - "c'est ce sodium que j'extrais de l'eau de mer et dont je compose mes éléments. … Mélangé avec le mercure, il forme un amalgame qui tient lieu du zinc dans les éléments Bunzen. Le mercure ne s'use jamais. Le sodium seul se consomme, et la mer me le fournit elle-même. Je vous dirai, en outre, que les piles au sodium doivent être considérées comme les plus énergiques, et que leur force électromotrice est double de celle des piles au zinc."

fifty miles an hour - "cinquante milles à l'heure." It is not clear if Verne meant nautical miles or statute miles.

sterring with "an ordinary rudder with a large blade, fixed on the back of the sternpost..." –

"Pour gouverner ce bateau sur tribord, sur bâbord, pour évoluer, en un mot, suivant un plan horizontal, je me sers d'un gouvernail ordinaire à large safran, fixé sur l'arrière de l'étambot, et qu'une roue et des palans font agir."

pilothouse --

"Le timonier est placé dans une cage vitrée, qui fait saillie à la partie supérieure de la coque du *Nautilus*, et que garnissent des verres lenticulaires. "

The pilot house is a little like the pilot houses of steamboats of the Mississippi or Hudson rivers, 6 feet on a side, which rises above the deck of the *Nautilus*. Four ports of lens-shaped glass in the walls permit the helmsman to see in all directions. – "C'était une cabine mesurant six pieds sur chaque face, à peu près semblable à celles qu'occupent les timoniers des *steamboats* du Mississipi ou de l'Hudson. Au milieu se manoeuvrait une roue disposée verticalement, engrenée sur les drosses du gouvernail qui couraient jusqu'à l'arrière du *Nautilus*. Quatre hublots de verres lenticulaires, évidés dans les parois de la cabine, permettaient à l'homme de barre de regarder dans toutes les directions. “

– “j'ai disposé des réservoirs d'une capacité égale à ce dixième, soit d'une contenance de cent cinquante tonneaux et soixante-douze centièmes, et si je les remplis d'eau, le bateau déplaçant alors quinze cent sept tonneaux, ou les pesant, sera complètement immergé. … Ces réservoirs existent en abord dans les parties inférieures du *Nautilus*.”

Nemo says he can move the *Nautilus* in the vertical plane with inclined planes attached at the center of flotation:

“Mais je puis aussi mouvoir le *Nautilus* de bas en haut et de haut en bas, dans un plan vertical, au moyen de deux plans inclinés, attachés à ses flancs sur son centre de flottaison, plans mobiles, aptes à prendre toutes les positions, et qui se manoeuvrent de l'intérieur au moyen de leviers puissants. Ces plans sont-ils maintenus parallèles au bateau, celui-ci se meut horizontalement. Sont-ils inclinés, le *Nautilus*, suivant la disposition de cette inclinaison et sous la poussée de son hélice, ou s'enfonce suivant une diagonale aussi allongée qu'il me convient, ou remonte suivant cette diagonale. “

The external floodlight:

“J'examinai alors l'installation de cet appareil dont la puissance était centuplée par des anneaux lenticulaires disposés comme ceux des phares, et qui maintenaient sa lumière dans le plan utile. La lampe électrique était combinée de manière à donner tout son pouvoir éclairant. Sa lumière, en effet, se produisait dans le vide, ce qui assurait à la fois sa régularité et son intensité. Ce vide économisait aussi les pointes de graphite entre lesquelles se développe l'arc lumineux. “

"The sea was distinctly visible within a radius of a mile around the *Nautilus.":* “La mer était distinctement visible dans un rayon d'un mille autour du *Nautilus*. “

The Salon:

"Pans coupés" (truncated corners of the salon):

"I followed Captain Nemo who by one of the doorways pierced in each truncated corner of the salon, rentered the internal passageways of the ship": “Je suivis le capitaine Nemo, qui, par une des portes percées à chaque pan coupé du salon, me fit rentrer dans les coursives du navire.”

"It was a large quadrilateral, with truncated corners, 10 meters long, six wide, and ten high": “C'était un vaste quadrilatère, à pans coupés, long de dix mètres, large de six, haut de cinq.”

“En parcourant ainsi le salon, j'arrivai près de la porte, ménagée dans le pan coupé, qui s'ouvrait sur la chambre du capitaine. A mon grand étonnement, cette porte était entrebâillée. Je reculai involontairement. “

The ladders or stairs, échelles:

“A peine l'étroit panneau fut-il refermé sur moi, qu'une obscurité profonde m'enveloppa. Mes yeux, imprégnés de la lumière extérieure, ne purent rien percevoir. Je sentis mes pieds nus se cramponner aux échelons d'une échelle de fer. “ chpt 8 para 2

“Je suivis le capitaine Nemo. à travers les coursives situées en abord, et j'arrivai au centre du navire. Là, se trouvait une sorte de puits qui s'ouvrait entre deux cloisons étanches. Une échelle de fer, cramponnée à la paroi, conduisait à son extrémité supérieure. Je demandai au capitaine à quel usage servait cette échelle.”

“Ceci dit, le capitaine Nemo se dirigea vers le panneau et disparut par l'échelle. Je le suivis, et je regagnai le grand salon. L'hélice se mit aussitôt en mouvement, et le loch accusa une vitesse de vingt milles à l'heure.” chpt 13 p 1