period. He constructed two submarine boats in France, and one in America. One of the former, the “ Nautilus,” was built with the direct encouragement of Napoleon in 1801. It was supplied with compressed air for respiration, and with it Fulton conducted a series of experiments under the direction of a commission of naval officers. He descended to a depth of 25 ft., and remained under water for fully four hours, placing below a vessel provided for the purpose a torpedo by which it was blown into fragments. As with his steam engine, so too with his submarine boats, the report of the commission charged with investigation· was so unfavourable that Fulton was much discouraged, and though he afterwards continued his labours in this direction, the results achieved by him were practically lost. Fulton’s boat, like Bushnell’s, was propelled by manual power, two horizontal screws being employed for propulsion, and two vertical screws for descending and ascending: it was built of wood with iron ribs, and was sheathed with copper.

The substitution of mechanical for hand power came later, and one of the first mechanically driven boats was the “ Plongeur,” built in France in 1863 from the designs of Charles Brun. This boat had a length of 146 ft. and a diameter of 12 ft., and was propelled by an 80-horse-power compressed-air engine. During the American Civil War the Confederates built a number of iron cigar-shaped boats; some were propelled by steam engines and some by hand. Each was armed with a torpedo containing 50 to 70 lb of powder carried at the end of a spar. These boats were known as “ Davids,” from their diminutive size as compared with the size of the ships attacked, and in 1864 one of the hand-worked boats, 50 ft. long, manned by a crew of nine men, successfully attacked the Federal ship “ Housatonic,” and sank her by means of a spar torpedo, but in so doing was herself sunk. It is claimed that the loss of the boat was due to faulty handling and not to inherent defect. Against the protest of her builder, she was immersed only to the hatch coaming; and the cover being left open, she was swamped and sunk by the wave thrown up by the explosion.

About the same time another hand-worked submarine, called the “ Intelligent λVhale, ” 26 ft. in length and 9 ft. in diameter, attracted some attention in America. An officer with two other persons dived with her in water about 16 ft. deep; the officer, in diver’s dress, left the boat through a manhole in the bottom, placed a torpedo under a scow and blew the latter to pieces.

In 1875 Mr. J. P. Holland produced his first plan for a sub- marine vessel, and in 1877 he constructed a small experimental boat, which embodied features now accepted as essentials in American design. His plan ensured that when, for the purpose of diving, water was admitted into compartments of limited size, the total weight of the boat and its contents should still be a little less than the total buoyancy. Immersion was maintained by the action of horizontal rudders, which gave a downward tendency so long as the boat had any forward motion, and there always remained enough surplus buoyancy to bring the boat to the surface on the stoppage of her propelling machinery. Any weight consumed on board was automatically compensated for by admission of water, so that the total weight remained fixed and constant; while the con­finement of the water to small compartments further secured a fixed centre of gravity. The securing of these qualities of fixed weight and fixed centre of gravity is essential, and the want of them has been the cause of failure in many other designs. With the necessarily slight longitudinal stability possessed by a submarine boat, any change of centre of gravity in the fore- and-aft direction has a no able effect on the angle of trim; and such a change may readily occur, for instance, from the surging of water in a large ballast-tank not completely full. An unintentional alteration of trim when the submarine boat is being propelled involves several possible dangers: in extreme cases the crew or some of the fittings may be thrown out of position, but in any case the path of the submarine is altered, and may tend either to too great immersion on the one hand, or to breaking the surface of the water on the other. From the risk of these dangers it is claimed by Mr Holland that his design is free. The first of his boats now under discussion was steered down and up inclines by her horizontal rudders, and motive- power was obtained from a petroleum engine. The tests to which she was subjected showed that inefficiency of the engine, difficulty of vision and trouble with the compass tended to destroy the boat’s usefulness.

In 1883 Mr Nordenfeldt, famous as an inventor in many directions, built a submarine boat at Stockholm. She had a length of 64 ft., a main diameter of 9 ft. and a displacement of 6o tons; she was propelled by a compound surface-condensing engine indicating 100 H.P., and on a measured-mile trial, not being submerged, attained a speed of 9 knots. Steam was supplied by an ordinary marine return-tube boiler, worked under forced draught, which could be fired as long as the boat was at the surface. Storage of steam was effected at the surface, and the steam thus stored was used to drive the engine in the submerged condition. To store sufficient steam two large tank reservoirs or cisterns were connected with the boiler, and the contents of boiler and tanks (8 tons of water in all) were raised to a temperature corresponding to 150 lb pressure. In preparing for submergence the firing of the boiler was stopped, and the steam given off by the heated water in boiler and tanks sufficed to propel the boat for a period. The smoke was driven out through two channels, which passed round the hull and pointed astern. The material of the hull was mild steel, the frames being 3 in. by 3 in. by 3/8 in., and the plating 5/8 in. to 3/8 in. in thickness; the depth to which she could safely descend was about 50 ft. When ballasted ready for a submerged trip, this boat showed only a very small dome for observation above the level of the water, the reserve buoyancy represented by this dome being but 1 cwt. To overcome this reserve two propellers working on vertical shafts were fitted in sponsons, one on each side of the boat, nearly amidships. These propellers were driven by a 6-horse-power engine, and drew the boat under water to the desired depth; an automatic contrivance, set in motion by the water pressure outside the boat, closing the throttle-valve when the safety limit of depth was approached. On coming to rest, the reserve buoyancy brought the boat again to the surface. When propelled by the main engines in the submerged condition, the boat was kept horizontal by means of two bow rudders operated by a plumb weight. The crew consisted of three men only, this small number rendering un­necessary the employment of artificial means of maintaining a pure atmosphere. The scheme of attack was to approach the hostile ship running at the surface until the danger of discovery was imminent, then to descend to the “ awash ” condition with only the dome above water, and finally to go below the surface and advance to striking distance entirely submerged, rising if necessary once or twice to allow the direction to be adjusted by observations made from the dome “ awash.” The weapon of offence employed was a Whitehead torpedo, carried outside on the bow and discharged mechanically. Several larger boats were subsequently built from Mr Nordenfeldt’s designs; they all involved the same principles, but were in some details made more efficient both for attack and defence.

The three main points insisted upon by Nordenfeldt were: (1) that his method of storing energy gave him a reservoir which was not liable to get out of order, could readily be repaired if necessary, and required for its manipulation no knowledge beyond that possessed by an ordinary engineer ; (2) that for submergence he relied on mechanical means easily controlled, adding, as a criticism upon the alternative method of descending by steering downwards, “ I need only point out the great risk of allowing an object 100 ft. long and of great weight to proceed in the downward direction even at a small angle, as the impetus gained would very easily carry it beyond a safe depth so quickly that they might not have time to check it ”; (3) that the bow rudders always secured a horizontal position when the boat was running submerged, which position he had found to be a *sine qua non* for a submarine boat.