examples of boats varies from as little as 5% to as much as 60% of their surface displacement. It is obvious that, the more water ballast carried, the less of some other weight of machinery or equipment can be carried on a given submerged displacement, and the whole problem resolves itself into making, the compromise which will best meet the requirements of the service for which the boat is intended. This fact has sometimes been lost sight of in discussions on this subject, which have tended sometimes to proceed on the assumption of a radical difference in character between boats of high reserve of buoyancy and those of low reserve, even to the extent of giving them the different names of "submersible ” and “submarine.” Another technical point in the design of submarines which has frequently been the subject of non-technical discussion is the desirability or otherwise of “ bow-rudders ” or “ hydroplanes.” This question depends on the form of the boat, and the manner in which it is proposed to handle her. and is unsuitable for discussion except in relation to the ascertained tendencies of a particular form under the vertical hydrodynamical forces which are set up by its propulsion through the water.

Similar considerations apply to the questions whether a submarine boat should have a separate means of propulsion for surface-running distinct from that fitted for submerged propulsion, and if so, whether it should consist of steam or internal-combustion engines. On account of the very limited capacity of even the best modern electric accumulator, any submarine which is intended to have a con­siderable radius of action must necessarily have heat engines of some description for surface propulsion and for charging bat­teries.

As to the type of heat engine, France was the only country which in 1910 had fitted steam engines in recently built submarines; and the general tendency was undoubtedly to use internal-combustion engines, of which those burning heavy oil are much less expensive in working than those using gasolene.

The general tendency in 1910 was to increase the size of submarine boats. Improvements in the design, apart from increase in size, depend principally on the improvements which may be made in the internal-combustion engines required for their surface propulsion, and in the improvement or possible elimination of the electric accumulators and motors for submerged propulsion, the weight of which is exceedingly great for the power obtained when compared with that which is obtained from heat engines.

It is the practice of all countries to keep secret the really important details of their submarine boats, to an even greater extent than those of ordinary warships. Some particulars, however, of the newer submarines of different countries are given below, prin­cipally to illustrate the progress in size and power.

In *France,* in 1901, Μ. Romazzotti, already re- ferred to as the designer of the “ Morse ” and “ Gustave Zédé,” produced two other boats, the “ Français ” and “ Algérien,” similar to the “ Morse.” Four vessels, the “ Sirène,” “ Triton,” “ Silure ” and “ Espadon,” of a modified “ Narval” type, were built from M. Laubeuf’s designs in 1901 ; two others of a similar type, the “Aigrette” and “Cigogne,” but of 170 tons surface displacement, were built in 1904, and two other still larger boats, the “ Circé” and "Calypso,” in 1905. These

two boats are (155 ft. long, 16 ft. beam, 10 ft. draught) of 350 tons displacement on the surface, 480 tons submerged. Two Diesel heavy oil engines are fitted to give 11¾ knots speed on the surface and two electric motors for use when submerged. Four boats of the “ Gnôme ” type, of 200 tons and 280 H.P. and 135 ft. in length, designed by M. Maugas, were commenced in 1899. In 1901 twenty small submarines of the “ Naïade ” type were commenced to Μ. Romazzotti’s design; they are 76 ft. in length and of 68 tons displacement, and have a surface speed of 8 knots and a speed of 4·5 knots when submerged. Their motive-power is electrical both for surface and submerged propulsion, except in the case of two boats which are provided with benzol motors for surface work. From 1905 to 1909, 34 boats of the “ Pluviôse ” type of twin-screw submersibles designed by Μ. Laubeuf were laid down; they have a displacement on the surface of 392 tons, and have engines of 700 H.P. and a speed of 12 knots on the surface, and 440 H.P. and a speed of 7¾ knots when submerged. Eighteen boats of the class have triple-expansion engines, and each of the remainder has two Diesel heavy oil motors for surface propulsion, while all have electric motors for use when submerged. Some of the steam-driven boats have traversed 730 m. in 82 hours, while the "Papin ” with oil motors ran 1200 m. from Rochefort to Oran in six days without calling at any intermediate port. In fig. 128 (Plate XXVII.) is shown the “ Vendemiaire,” one of the boats of this class. The twin- screw submarines of the “ Emeraude ” class, six in number, de- signed by M. Maugas and laid down in 1906, are of approximately the same displacement as the “ Pluviôse ” class and of about the same speed; their motive-power consists of two Diesel heavy oil engines on surface and electric motors when submerged. A considerable advance in length and displacement was made in 1907, when the “ Mariotte,” 216 ft. in length, 522 tons displacement on the surface, and 615 tons submerged, the “Archimède,” 199 ft. in

length and 568 tons displacement on the surface and 797 tons submerged, and the “ Admiral Bourgois,” 181 ft. in length and 555 tons surface displacement, were laid down. The H.P.s of these three submersibles are 1400, 1700 and 1500 respectively at the surface, giving a speed of 15 knots (submerged speed 10 knots).

After the completion of the last boat of the “ Adder ” class already referred to, a period of about three years elapsed before the acquisi­tion for the *United States* navy of any additional submarine boats. The “ Octopus,” which underwent extended trials in 1907, was designed by the Electric Boat Company, the successors of the Holland Boat Company, and marked a great advance in all respects over the earlier boats. She is a twin-screw boat, having two torpedo tubes instead of one, as in the previous boats; she is of about 273 tons displacement submerged and 255 tons on the surface, and is credited with maximum trial speeds of 11 knots on the surface and 10 knots submerged. Three other boats, the “ Cuttlefish,” “ Tarantula ” and “ Viper,” generally similar to but somewhat smaller and less powerful than the “ Octopus,” were also completed during 1907 and 1908; and the “ Snapper,” “ Bonita,” "Stingray” and “ Tarpon,” of the same size as the “ Octopus,” in 1909. The “ Salmon,” a boat similar to the “ Octopus,” but of 278 tons displacement on the surface, 360 tons submerged and carrying four torpedo tubes, was completed in 1910, and is credited with trial speeds of 13 knots on the surface and 9½ knots submerged. In July 1910 this boat made the ocean passage of about 700 to 800 m. from Quincy, Mass., to Kingston, Bermuda, in four days, and returned in about the same time, proving herself remarkably seaworthy for so comparatively small a boat in the rough weather encountered. Several similar boats were in 1910 under construction.

ln 1900 *Great Britain* ordered five submarine boats from Messrs Vickers, Sons & Maxim, at Barrow, who, by arrangement with the Electric Boat Company of New York, were enabled to embody in their designs all the features of the Holland boats of the “ Adder ” class, which these first British submarines resembled in size and most other respects, the length being about 63 ft. and submerged displacement 120 tons. Subsequent British submarines of the A, B and C classes were designed by Messrs Vickers, Sons & Maxim under instructions from the Admiralty. The progress in size and power has been continuous, and the departure from the original “ Holland ” type more and more marked with each successive new design. Table XX. indicates the various steps. All the boats there mentioned, except A13, which has heavy oil engines, are fitted with gasolene engines for surface propulsion. D1, which also has heavy oil engines, was completed in September 1909, and was the first of a new series of boats for the design of which Sir Philip Watts was personally responsible. She passed through her trials, and seven similar boats were in 1910 under construction. Fig. 129 (Plate XXVIII.) gives a view of C32, while fig. 130 shows D1 under weigh on the surface, and fig. 131 a flotilla in Portsmouth Harbour.

*Russia* purchased the Lake demonstration boat “ Protector ” in 1904. This boat is 65 ft. long, 115 tons displacement on the surface and 170 tons submerged. The surface speed is stated to be 9 knots and the submerged 6 knots. A larger boat, of 135 tons displacement—the “ Simon Lake ”—was also purchased, and four others of the same size built in 1904-1905. In 1907 another small “ Lake ” boat of 110 tons was obtained, and in 1908 and 1909 seven larger vessels, 125 ft. long, 14 ft. beam, 450 tons on surface, 500 tons submerged, 16 knots speed on surface with petrol engines, and 6½ knots submerged, with electric motors. Of the “ Holland ” type Russia has obtained a considerable number; fifteen of these are from 106 to 175 tons on the surface, and one is 184 ft. long, 12 ft. beam, 11 ft. deep and 360 tons on the surface. She has also obtained three boats of the “ Germania ” type, 131 ft. long, 197 tons on the surface, as well as a specimen of a small submarine of 17 tons hoisting weight driven by electric accumulators only, giving 8 knots on the surface and 6 knots submerged, and armed with one torpedo tube. The large boats of the “ Lake ” type are driven by engines of 1200 H.P., and are stated to carry an armament of two 3-pdr. and two machine guns in addition to their four torpedo tubes. Three of the Russian submarines under construction in 1910 were 500 tons displacement on the surface.

*Germany* did not build submarines until 1906, when U1 was launched at the Germania Works, Kiel. She is 139 ft. long, 11 ft. 9 in. beam, 7 ft. 9 in. draught and 240 tons on the surface, being

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| Table XX. | | | | | | |
| Name or Class of Boat. | Year of Completion. | Length. | Breadth. | Submerged Displacement. | Horse- Power of Engines. | Speed on Surface. |
| Ai . . | 1903 | Feet.  100 | 11'9\* | Tons.  2o6 | 35o | Knots.  9, |
| A2-A4 . | 19o4-1905 | 99 | 12'8’ | 205 | 450 | 1o∣ |
| A5-A12. | 1905-1906 | 99 | 12'8\* | 205 | 600 | I1i |
| A,3d | 19o6-1907 | 99 | 12’8' | 205 | 5∞ | 111 |
| Bi-Bii. . | 1905-1907 | 135 | 13' 6' | 314 | 600 | 12⅛ |
| Cι-C17. . | I9o7-I909 | 135 | 13z6\* | 3M | (MX) | 12 ⅛ |
| C19-C38 . | 1908-1910 | 135 | 13' 6\* | 320 | 6OO | 12i |