THE STABILITY OF SUBMARINES.

THE construction of submarines for the Royal Navy began about five years ago. On March 31, twenty-five vessels of the class had been completed, fifteen were building, and twelve more were projected in the Navy Estimates for 1906–7. France at the same date had thirty-nine submarines completed, and fifty building or projected. Russia had thirteen vessels completed and fifteen building. The United States had eight vessels completed and four building, while Congress has recently sanctioned a special vote of 200,000*l.* for further work on submarines. Germany, Italy, and Japan as yet have done but little, but they are moving in the same direction. An American engineer, Mr. Holland, has exercised the greatest influence on recent submarine design, having worked at the problem for thirty years, and proved himself a worthy successor of his fellow-countrymen Bushnell and Fulton, who were pioneers in submarine construction in the closing years of the eighteenth century and the commencement of the nineteenth. The first five British submarines, ordered in 1900, were repetitions of a type designed by Mr. Holland, tried and approved by the United States Navy Department. Great developments have taken place in later British submarines. Those first built had displacements of 120 tons, surface speeds of eight to nine knots, and gasoline engines of 160 horse-power. Vessels now building have displacements exceeding 300 tons, a surface speed of thirteen knots, and gasoline engines of 850 horse-power. The cost of the earlier vessels was about 35,000*l.*; that of the later vessels must be twice as great. Other countries have taken similar action, and some are building still larger vessels.

British submarines are kept continuously at work, and this experience has yielded valuable information leading to successive improvements. The vessels chiefly used for experimental purposes up to date belong to the "A" class—200 tons in displacement and ten knots surface speed. Vessels of this class consequently have been most before the public. Their active employment has not been free from accidents, but, having regard to novelty of type and special risks which unavoidably accompany the power of submergence, it is a matter for congratulation that these accidents have not been more numerous and serious in their consequences. Official inquiries have been made into the causes of accidents, and reports have been published. In the opinion of the writer these proceedings showed a tendency to minimise risks necessarily encountered in working submarines. He consequently undertook a lengthy series of calculations for typical submarines of different dimensions, in order to ascertain their conditions of stability in various conditions which occur on service. The results for one class are embodied in a paper presented to the Royal Society on May 3, which paper contains also the results of similar calculations made for a cruiser of ordinary form. The distinctive conditions of submarines were emphasised by comparing these results, and the editor of NATURE has suggested that an explanation in popular language of the principal conclusions, based on the investigations, may be of general interest.

Submarines are generally "cigar-shaped," with circular or nearly circular cross-sections. This form is adopted in order to provide, with a minimum expenditure of weight, structural strength sufficient to meet severe external fluid pressures which may come upon the hulls if submarines sink to considerable depths. Such depths are not reached intentionally, but experience shows that they may be attained accidentally, and that very quickly.

In ordinary vessels the freeboard is considerable, and the sides are approximately vertical between the lightest draught reached on service and the deepest (load) draught; consequently, within these limits of draught, horizontal sections of the vessels coincident with the water-surface—known as *planes of flotation*—remain practically constant in form, area, and moments of inertia. In cigar-shaped submarines, with circular cross-sections, the freeboard is small, and the lightest draught of water bears a large proportion to the diameter of the largest circular cross-section. For the typical submarine dealt with in the Royal Society paper, the extreme breadth (diameter of largest cross-section) is a little more than twelve feet, and the lightest draught of water is about ten feet. The circular form of cross-section involves rapid diminution in lengths, breadths, areas, and moments of inertia of successive planes of flotation as the draught of water is increased from light to load. These changes are accompanied by rapid and considerable losses in the stability, and the conditions differ radically from those of ordinary ships. For the typical submarine the extreme length is 150 feet, and breadth extreme 12·2 feet; but the length of water-line at the lightest draught is only 94 feet, and breadth 8·2 feet. When the draught of water is increased eighteen inches (by admitting water-ballast) and the vessel is prepared for diving, the length at the water-line falls to 41 feet, and the breadth to 3·6 feet. In the cruiser of ordinary form an equal change of draught produces small change in length, breadth, and area of the planes of flotation, and these dimensions are practically equal to the extreme length and breadth of the vessel. For the cruiser the moments of inertia of successive planes of flotation about their principal axes remain nearly constant within these limits of variation in draught; whereas for the submarine moments of inertia diminish rapidly as the draught of water is increased. In the cruiser the extreme length is 260 feet, and the metacentre for longitudinal inclinations is 352 feet above the centre of buoyancy at light draught, and 328 feet when the draught is increased by eighteen inches. In the submarine the extreme length is 150 feet, but the corresponding height of longitudinal metacentre above centre of buoyancy is only 37 feet at lightest draught, and falls to $1\frac{1}{4}$ feet when the vessel is prepared for diving. At the lightest draught the power of the submarine to resist longitudinal inclinations (changes of trim) is relatively small; in the diving condition it is diminished almost to vanishing point. It will be understood, therefore, that when a submarine is prepared for diving every man has to remain at his station, and no weights must be moved; every opening into the interior must be closed hermetically. The reserve of buoyancy is extremely small in the diving condition. A submarine of more than 200 tons weight may have only 400 to 800 pounds reserve—representing 40 to 80 gallons of water.

Even at their lightest draughts the reserve of buoyancy of submarines is very small as compared with that in other vessels. In good examples it is 6 per cent. of the corresponding displacement—little more than half the lowest percentage accepted for low-freeboard monitors when fully laden, and about one-fourth the corresponding percentage for the deepest laden cargo steamers. Openings into the interior are placed at the tops of conning towers at a considerable height above water, and Admiralty regulations provide that all openings shall be closed before water-ballast is admitted to bring a vessel into the diving condition. Further, it is now provided that before proceeding at full speed at the surface, the maximum reserve of buoyancy shall be secured by emptying ballast tanks. One of the most serious accidents that have occurred to British submarines—that to A 8—was unquestionably due in great measure to proceeding at full speed with about half the maximum reserve of buoyancy, certain tanks containing water-ballast. The vessel was driven under water as she gathered speed, dipped her bow suddenly, brought the open top of the conning tower to the water-level, was partly filled, and foundered.

Maintenance of the full reserve of buoyancy and lightest draught of water when proceeding at the surface increases safety in two directions. It secures much greater longitudinal stability, and diminishes the tendency to plunge produced by the relative motions of the water surrounding the vessel, especially at the bow. These motions are largely discontinuous, broken water being piled upon the bow, and the phenomena being of such a character that only direct experiment on models or vessels can give accurate information. Such experiments have been made both in this country and abroad, and they indicate the occurrence of a tendency to plunge at certain critical speeds. The problems are still only partially solved, but it is certain that the maximum reserve of buoyancy should be maintained. It also appears desirable to keep the vessels on an even keel, since a cigar-shaped form has then its maximum longitudinal stability for a given mean-draught of water. In the Royal Society paper calculations are recorded showing the diminution of stability accompanying changes of trim in submarines.

In modern submarines of large size the operation of diving is performed when the vessels have headway. Horizontal rudders, controlled by skilled men, are employed as the active means of depressing the bow. The pressures on the upper surface of the vessel resulting from the relative movement of the surrounding water develop a vertical component acting downwards which overcomes the small reserve of buoyancy and the vertical component of the pressures on the rudder. The submarine then moves obliquely downwards. When the desired depth below the surface has been reached the steersman operates the horizontal rudders in such a manner that the vessel shall advance on a practically horizontal course, although it really is an undulating one. Watchfulness and skill are necessary to achieve this result, and there must be no movements of men or weights which would vary the position of the centre of gravity. If such movements become necessary—as, for example, when torpedoes are discharged—compensation must be arranged to take effect at once. Failures to comply with these conditions may involve serious consequences, and have caused submarines to dive to great depths. With trained and disciplined crews such accidents are rare. Plans for automatic maintenance of any desired depth—similar to those used in locomotive torpedoes—have been brought forward and tried; but for large submarines manual control has been found preferable. In small submarines it has been found possible to dive without headway by varying the volume of displacement, admitting water into suitable chambers from which it can be readily expelled when the desired depth has been reached, and a balance restored between weight and buoyancy. Such methods involve the necessity for minute and rapid adjustments, which can be secured on a small scale much more readily and certainly than on a large scale. As a consequence, horizontal rudders and headway have been generally adopted for large submarines, and have answered well on the whole. One great advantage of the plan is that when headway ceases the horizontal rudders become inoperative, the small reserve of buoyancy reasserts itself, and the submarine comes to the surface. The other system—varying the volume of displacement—especially when applied to large vessels, involves risks of reaching great depths in a short time before buoyancy can be restored. This is recognised in vessels which work on that system, and detachable external weights are fitted, so as to restore buoyancy in cases of emergency.

There has been a considerable increase in the speed of submarines, both at the surface and when submerged. Our latest types are said to have surface speeds of thirteen knots and a radius of action of 500 miles with their gasoline engines, while the under-water speed is nine knots and radius of action 90 miles. These higher speeds are attainable, no doubt, but they necessarily involve greater risks, especially in the diving condition. Pressures on horizontal rudders increase as the *squares* of the speeds, and the extreme sensitiveness of submarines when submerged to the action of external forces tending to produce changes of trim must demand much greater watchfulness, skill, and promptness of action on the part of steersmen than are now required, if greater speeds are to be attained under water. The risks of attaining rapidly excessive depths of submergence must increase as speeds are raised, and they are now far from negligible. At the lightest draughts increase of speed would also involve greater risks of accidental plunging. Exhaustive experiments are necessary, therefore, before designers of submarines commit themselves to the production of vessels having much greater surface speeds, and still more of vessels having much greater under-water speeds. Submarine design is not a task to be lightly undertaken by amateurs; it requires thorough experimental and scientific treatment by competent naval architects, who should be furnished by naval officers with the strategical and tactical conditions to be fulfilled in the completed vessels, and should ascertain what is involved in the fulfilment of these conditions.

W. H. WHITE.

THE RISE AND PROGRESS OF THE ZOOLOGICAL SOCIETY.[1]

IT was a happy thought on Mr. Scherren's part to tell the story of the Zoological Society of London, and he is to be congratulated on the success with which he has accomplished his evidently congenial task. The history of a development is always interesting, especially when it is still progressing, and there is, moreover, a strong personal interest in the book, since many eminent workers, whose names and deeds are familiar, have cooperated in various ways in furthering the welfare of the society since its inception in 1826. Mr. Scherren's book is not only a careful contribution to the history of zoology in Britain during the last eighty years, but is at the same time good reading for its revelation of what goes on behind the scenes in a scientific society, and for its record of many interesting events in what is familiarly called the "Zoo."

On November 29, 1822, John Ray's birthday, a bud from the Linnean Society formed itself into a "Zoological Club," which four years afterwards took shape as the Zoological Society. There were 342 members at the close of the year, and there are now ten times as many. In 1828, when the gardens were opened to the public, there were about 600 specimens, and there is now a specimen for each F.Z.S. A farm for breeding purposes and experimental work (from which nothing very noteworthy ever resulted) was established in 1829 at Kingston Hill, and scientific meetings began to be held in 1830. Such were the

---

[1] "The Zoological Society of London: a Sketch of its Foundation and Development, and the Story of its Farm, Museum, Gardens, Menagerie and Library." By Henry Scherren, F.Z.S Pp. xii+252; 12 coloured plates, 50 uncoloured plates, 9 plans. (London: Cassell and Co., Ltd., 1905.) Price 30*s*. net.