made (the fastest torpedo up to 1898 having a speed of 29 knots for 800 yds.), it was of no advantage to make them, as they could not be depended upon to run in a straight line from a stationary point for more than 800 yds., while from a ship in motion good practice could only be ensured at a reduced range. It was obvious, therefore, that to increase the effective range of the torpedo, these errors of direction must be overcome by some automatic steering arrangement. Several inventors turned their attention to the subject, nearly all of whom proposed to utilize the principle of the gyroscope for the purpose. The first which gave any satisfactory results was an apparatus devised by Ludwig Obry—an engineer in Austria—and tried by the Italian government about 1896. These trials demonstrated the feasibility of accurately and automatically steering a torpedo in a direct line by this means. Messrs Whitehead & Co., of Fiume, then acquired the invention, and after exhaustive experiments produced the apparatus which is now fitted to every torpedo made. It is based on the principle that a body revolving on a free axis tends to preserve its plane of rotation. A gyroscope with plane of rotation parallel to the vertical axis of the torpedo will have an angular motion if the torpedo is diverted from its original course. This angular motion is employed to actuate the steering mechanism by operating an air motor connected with the rudders, and keeping the torpedo in the line of discharge. The apparatus consists of a flywheel caused to rotate by a spring, the barrel on which the latter is wound having a segmental wheel which gears into a toothed pinion spindle of the flywheel. Owing to the diameter of the segment being much greater than the pinion, a rapid rotatory motion is imparted. The spring is wound up by a key from outside the torpedo, and kept in tension until the pro­jectile is discharged, when the spring is released by the air lever being thrown back, which admits air to the engine; the gyroscope is then freed and set in motion with its plane in the plane of the vertical axis of the torpedo as it was in the launching tube.

Assuming now that the course of the torpedo is diverted by any cause, its axis will move or perform a certain angular motion with regard to the plane of the flywheel, which will have the same result as if we consider the conditions reversed, *i.e.* as if the plane of rotation of the flywheel were altered and that of the axis of the torpedo remained the same. The axis of the flywheel performs a relative angular motion which it imparts to a crank actuating a servo-motor worked by compressed air, and connected with the rudders of the torpedo, moving them in the opposite direction to that in which the torpedo was diverted from its original course. Thus all inaccuracies of flight due to errors of adjustment, mis­calculation of deflexion, or even damage to some part, are elimin- ated. As long as the gyroscope is in good order the torpedo is bound to run in the line it was pointing when the flywheel was started. It is placed in the after-body of the torpedo, as indicated in fig. 2.

The efficiency of the Whitehead torpedo has thus been enormously increased, and more accurate practice can now be made at 2000 yds. than was formerly possible at 800 yds. This adds con­siderably to the chances of torpedo-boats attacking ships, even in day-time, at sea or at anchor, and will render further protection necessary against this weapon. Against a ship in motion there is still, however, the calculation as to her speed and the distance she will travel before the torpedo reaches her. Should this be miscalculated, an increased range for torpedoes will magnify the error. For instance, a 30-knot torpedo will travel 1000 yds. in a minute. If aimed at a ship on the beam assumed to be steaming 15 knots an hour, to reach her when 1000 yds. distant the torpedo must be discharged at a point 500 yds. ahead of her. But if the ship is actually steaming 12 knots, she will have travelled only 400 yds. in the minute, and the torpedo will be 100 yds. in advance, of her. If discharged at a range of 500 yds., such a miscalculation causes an error of only 50 yds. or 150 ft. But if the object is 300 it. long, and her centre was taken as the target, her bow would be just at the spot the torpedo would reach in thirty seconds. It would seem, therefore, that increased velocity of torpedo is necessary before the full advantages of the gyroscope can be realized. Now the range of the torpedo is entirely dependent upon the store of energy which can be carried; upon, therefore, the capacity of the air reservoir, the maximum pressure it can stand, and on the effici­ency of the propelling engines. The speed over a given range is also dependent upon these factors; the maximum speed being limited by the strength of the engines and other parts. Improvements in steel, manufacture have permitted the use of much higher pressures of air and the construction of air-chambers able to with- stand the pressure of 2000 lb to the sq. in. with the same weight of air-chamber. This has enabled increased range without reduction in speed to be attained, or conversely, increased speed at shorter ranges. By improvement in the engines which are now of the Brotherhood 4-cylinder central crank type further gains have been effected.

Having reached the limit of pressure and endurance of air- chambers with present materials without undue increase of weight, the designer had to seek additional energy in another direction. Now the energy obtainable from a given weight of compressed air is dependent upon the volume of air available at the working pressure of the engines. At a constant pressure this volume of air is proportionate to its absolute temperature. If then the air be stored cold and highly heated before delivery to the engine the available energy from a given weight will be greatly increased. By this means we obtain the equivalent of a larger and heavier air-chamber without the increased weight such would involve.

As originally used a quantity of hydrocarbon fuel was placed in the air-vessel. Upon discharging the torpedo this fuel was automatically ignited and the contents of the air-chamber were heated. Unless, however, the combustion could be regulated there were serious risks of abnormal pressures, of overheating and weakening the air-vessel. Devices have been applied to overcome this liability, and other methods devised to obtain the same result.

By the use of heating and thereby increasing the volume of air in proportion to the rise of temperature the extra volume will allow of an increased speed for a given range or a greater range without increase of speed. The limit to the development of this system seems to be the temperature the materials will stand, but even at this early stage it has added several knots to the speed of this wonderful weapon.

*Torpedo Carriages and Discharge.—*As no gun which is ineffi­ciently mounted can give good results, so the best torpedo is valueless without a good carriage or system of discharge. In the early days of the Whitehead, discredit came upon it because the importance of this was not sufficiently realized; and an erratic course under water was in nine cases out of ten due to a crude method of discharge. A delicate piece of mechanism was dropped into the water from a height of several feet, and naturally suffered internal derangement. Gun-ports were then used for the purpose, but now a special orifice is made, to which the torpedo carriage is fitted with a ball- and-socket joint—forming a water-tight aperture—so that this carriage or tube may be only 2 or 3 ft. above the water-line. The ball-and-socket joint enables it also to have a considerable angle of training. Originally the torpedo was pushed out by a rod acted upon by compressed air, in which case the carriage was a simple frame. The rod, pressing against the tail with some force, was apt to damage or disarrange the rudders, so the air-gun took the place of rod impulse. Here the torpedo fits closely in a tube or cylinder with an opening at the rear made air-tight when closed. At the desired moment compressed air is admitted to the rear part of the cylinder and blows the torpedo out. Gunpowder then superseded air for this operation; and now this has given place to a small charge of cordite, which does not leave any deposit on the inside of the cylinder. There is a double risk in the use of locomotive torpedoes from above water. (1) The charge may be exploded by hostile fire. Though mainly consisting of damp gun-cotton, which is not readily ignited, the dry primer and detonator may be struck, which would lead to a disastrous explosion. (2) The air- chamber is also a source of danger. As it contains air compressed to a high degree of tension, experiments have shown that if struck by a small shell it may burst with great violence; and as it offers a considerable mark, this is not an improbable event in an action. An instance of the danger of above-water torpedo tubes occurred in the Spanish-American War at the battle of Santiago. A shell entered the “ Almirante Oquendo ” and struck a 14-in. torpedo in the tube. The charge detonated, causing a fearful explosion and practically wrecking that part of the vessel. The development of moderate-sized quick-firing guns has increased this risk. Hence we find the use of above-water torpedo tubes now mainly confined to torpedo and other craft too small for submerged discharge.