NAVAL WARFARE WITH STEAM.

SECTION I.

On the Application of Steam Power to Ships of War.

1. It would be foreign to the plan of this work to enter into details respecting the invention of the steam-engine, or to describe the gradual improvements which it has subsequently undergone; [a] a brief notice only will be given of the several steps by which it has been rendered applicable to the purposes of navigation.[b]

In the beginning of the eighteenth century the Steam-Engine, or, as it was then called, the Atmospherical Engine, produced its effect solely by the admission of steam into the cylinder at its lower extremity; the steam by its elasticity forced the piston to the upper part of the cylinder, when, a vacuum being caused by a sudden condensation of the steam in consequence of a jet of cold water being introduced, the pressure of the atmosphere on the upper surface of the piston caused this to descend: steam being again admitted below, the piston was forced upwards; and, again, a vacuum being formed as before, the atmosphere caused the piston a second time to descend. This alternate ascent and descent of the piston caused corresponding movements of the pump-rod, by which means water was raised. The steam-engine was long employed for this purpose only.

[a] For a full explanation of the marine steam-engine in its present improved state, the reader is referred to the treatise on that important subject by Mr. Thomas J. Main, Mathematical Professor in the Royal Naval College, Portsmouth.

[b] The author wishes it to be understood that this historical and descriptive notice relating to steam is introduced only for the benefit of the general reader, or of those officers who may not have had the advantage of studying the subject at the Royal Naval College.

2. The first improvement by Watt consisted in admitting the steam alternately at the bottom and top of the cylinder, so that, when the vacuum was formed below the piston, the pressure of the steam above caused the piston to descend; and the vacuum being then formed above the piston, the pressure of the steam below caused it to ascend. In this manner a reciprocating motion of the piston was maintained; and, as the pressure of the steam could be made to exceed that of the atmosphere, a greater degree of power was obtained; and this augmented power was enabled to act uniformly on the piston. The patent for this great improvement was obtained by Mr. Watt in 1769; and, in 1780, Pickard took out one for converting the reciprocating motion of the pump-rod into a rotatory motion. This was effected simply by means of a crank, and in the following year Mr. Watt invented what he called the sun and planet wheel-work, by which the same end was gained as by the crank; and this rotatory motion was a great step towards the employment of the steam-engine as a means of propelling ships on the water. At length, in 1802, the first boat with paddle-wheels propelled by steam was constructed.

3. It would be improper to dwell on the supposed project of a Spanish captain named Garay, who is said, in 1543, to have exhibited a vessel propelled by poles to which motion was communicated by boiling water, or on the unsuccessful experiments made in France in 1774-5, and in America in 1783, to give motion to a vessel furnished with paddle-wheels, which were made to revolve by means of a small steam-engine; but it deserves to be particularly mentioned that in the years 1788-9 experiments were made at Dalswinton in Scotland on the use of paddle-wheels, at first moved by mechanical means, for the propulsion of vessels on water. These were commenced by a Mr. Millar of that place, and were conducted under his auspices by Messrs. Taylor and Symington; and to the former of these two engineers is ascribed the idea of employing steam-power to give motion to the wheels, which was

afterwards put in practice by the latter. Mr. Symington's experiments were carried on under the patronage of Lord Thomas Dundas; and, in 1789, a boat called the 'Charlotte Dundas,' propelled by a double stroke engine (Watt's patent) and paddle-wheels, was tried upon some water in the neighbourhood of Dalswinton; it is said to have been moved at the rate of 5 miles in an hour. Experiments of the same nature continued to be made by the abovenamed gentlemen; and, in 1802, Symington built two steamboats which conveyed goods on the Forth and Clyde canals.

4. The American Chancellor Livingstone had, in 1798, made an unsuccessful attempt to construct a steamboat, to be used on the Hudson; and, in 1803, being in France, he constructed a steam-vessel, in conjunction with Fulton, to be used on the Seine: this also failed, but Fulton afterwards visiting England, was introduced to Symington, and was, by that engineer, allowed to inspect the vessels which he had constructed. Fulton subsequently returned to America; and, in 1807, he completed a vessel with paddle-wheels, moved by a steam-engine which had been executed by Boulton and Watt in England: this vessel, called the 'Clermont,' was the first which was employed as a passage-boat, and its first voyage was made on the Hudson, from New York to Albany.

5. The first steamboat which plied on the Thames is said to have been brought from the Clyde by a Mr. Dawson in 1813: as a speculation the measure failed; but, from the year 1815, steam-vessels have constantly been employed for the conveyance of passengers up and down the river.

6. A Mr. Stevens, junior, of New York, is said to have been the first who took a steamboat to sea; this was about the year 1804, and the vessel is said to have been moved by a machine resembling a smoke-jack: this may consequently be considered as the first application of the Screw Propeller in navigation. The first ship propelled by steam which crossed the Atlantic was the 'Savannah,' a vessel of 350 tons burthen. It was built

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and equipped at New York, and, in 1819, it proceeded direct to Liverpool; from thence it proceeded to St. Petersburg, and subsequently recrossed the Atlantic, having used steam during the whole voyage. Between the years 1842 and 1845 Her Majesty's steam sloop 'Driver,' commanded by Captains Harmer and Hayes, made the circuit of the earth.

7. It may be interesting to know that as long since as the year 1785 Mr. Bramah obtained a patent for a submerged propeller on the principle, it is said, of a windmill-sail; subsequently patents were obtained by other persons for propellers constructed on similar principles, which being moved by mechanical means, sufficiently demonstrated the efficiency of that construction. In 1836, Captain Erecsson, a native of Sweden, obtained a patent in England for a screw-propeller, and a steam-vessel constructed by that engineer with the screw at the stern was tried on the Thames, in presence of the First Lord of the Admiralty and the Surveyor General of the Navy; the success is said to have been complete, but the new machine failed to gain the approbation of the British Government. The subject being, however, brought to the notice of Captain Stockton, of the United States' Navy, then in London, this officer strongly recommended it to the authorities in America. Under his direction an iron vessel with a screw propeller was constructed in England; and, after crossing the Atlantic, it was employed on the Delaware and Rariton Canal. This vessel afforded the first practical evidence of the success of the screw as a means of propulsion, both for the inland waters of a country and on the high seas.

8. The greatest improvement which has been made in the manner of applying steam as a moving power, with respect to the union of force with economy, has consisted in what is called the expansive principle. It is at present the custom to allow steam whose force of elasticity is expressed by a pressure varying from 25 lbs. to 40 lbs. per square inch, including the pressure of the atmosphere, to enter the cylinder of a steam-engine;

and when the piston has moved through a space varying from two-fifths to three-fifths of the whole stroke or range of the piston, to close the steam-slide so that no more steam may enter till the piston is at the end of the stroke, leaving that which has been admitted to complete the stroke by its expansive power.

9. Now, if steam of a given elasticity be allowed to act uniformly on the surface of the piston through the whole length of the stroke, the efficient momentum of the steam would be expressed by $p\,a\,l$; p denoting the pressure of the steam on a square inch of the surface of the piston, a the area of that surface in square inches, and l the length of the stroke also in inches. But if the steam be cut off after the piston has moved through a part of the stroke which is expressed by $m\,l$ (m being a proper fraction), the efficient momentum of the expanded steam during the remainder of the piston's movement will be expressed by the integral of $\frac{a p m l d x}{x}$ between the limits $x = m\,l$ and $x = l$: (the density, elasticity, or pressure of the steam in any part of the cylinder being inversely proportional to the space, or distance of the piston from its place at the time the steam was cut off.) This integral is $a\,p\,m\,l$ hyp. log. $\frac{1}{m}$, which added to $a\,p\,m\,l$, the momentum of the steam previously to being cut off, the sum is the efficient momentum of the steam thus acting expansively. If $m = \frac{2}{15}$, the hyp. log. of $\frac{1}{m}$ is equal (nearly) to 2; and the whole momentum becomes $\frac{1}{3}\,a\,p\,l$ nearly. Thus, with $\frac{2}{15}$ths, or less than one-seventh, of the quantity of steam, consequently of the quantity of fuel,[a] a power is obtained equal to one-third of that produced by the whole of the steam if allowed to act unexpansively; it

[a] Since the pressure on a piston varies with the weight or density of the steam, and the weight of a body of steam is equal to the weight of the water which generates it, it follows that if the quantity of fuel consumed when the steam is employed unexpansively be represented by 1, the quantity consumed will be expressed by $\frac{1}{7}$ when the steam is used expansively.

follows also that, with steam to be used expansively, whose elastic force is $2\frac{1}{2}$ times as great as that of steam used unexpansively, if it be cut off when the piston has moved two-fifteenths of the whole length of stroke, the effective momentum will be the same as that which would be produced by the steam of less elasticity when used unexpansively: while the consumption of steam, and therefore of fuel, in the former case is only one-third ($= 2\frac{1}{2} \times \frac{2}{15}$) of the consumption in the latter case. It must be observed, however, that, in order to resist a double expansive force of steam, the machinery ought to have a double strength, and would, consequently, be twice as heavy. In the above investigation no notice is taken of the effects of friction on the movement of the piston; this friction, and the imperfect vacuum in the cylinder, are causes of considerable loss of power in all steam-machinery.

10. Experience seems to show that these retarding forces may, together, be estimated at about one-fifth of the whole power of the steam; and there is a further diminution, when the steam acts expansively, on account of the loss of heat occasioned by the expansion of a gas; and this, when the steam is allowed to expand to double its original volume, has been estimated at about one-twentieth of the whole power. It follows, as is observed by Messrs Seaward and Capel,[a] that there may come a time during a stroke when the power of the steam becomes less than the force of resistance against the piston, in which case the piston would stop if it were not for the momentum previously acquired. The same gentlemen observe that there must consequently, in practice, be a limit to the expansive principle; and it is concluded that a cylinder having a 3 feet stroke, in which the steam is cut off at one-third of the range, would be nearly as efficient as a cylinder having a 6 feet stroke in which the steam is cut off at one-sixth, the consumption of fuel being equal. It is recommended that, for marine engines, the expansive

[a] Copy of Letter to the Hon. H. L. Corry, M.P., on the use of High Pressure Steam in the Steam-Vessels of the Royal Navy. 1846.

force of the steam should not exceed 10 or 12 lbs. per square inch above the pressure of the atmosphere; and Messrs. Seaward and Co. propose that, for engines of great power, the steam should be cut off at one half or three-fifths of the stroke.

11. Marine engines of the present day are said to be from 20 to 50 per cent. more powerful in giving motion to ships than those of former times; this greater speed, and the diminished consumption of fuel, are due to the adoption of the *wave principle* in forming the bows of ships, the improved construction of machinery, and the employment of more elastic steam.

12. The only means of propelling ships by the agency of steam which have as yet been brought to the test of experiment, and which have been generally adopted, are the Paddle-Wheel and the Screw; but both of these, in their forms, have been variously modified.

13. The reciprocating motion of the piston rods in the two steam cylinders of the engine being made to act, by means of cranks, on the shaft or common axle of the paddle-wheels, causes these to take a revolving motion about that axle; and the reaction of the water against the floats or paddle-boards as they revolve, impels the vessel forward.

14. When the paddle-boards are permanently fixed, as they usually are, in planes passing through the shaft, they necessarily enter the water obliquely; and it is only when any one board is in a vertical position, under the shaft, that the reaction of the water against it is direct. In other positions the boards press against the water in directions oblique to the line of the vessel's motion: on entering the water the boards exert a pressure downwards, while in emerging they lift up a body of water, and both these actions cause violent strains and vibrations in the vessel.

15. The *Dip*, or the immersion of the lowest paddle-board in the water, should in general be equal to the breadth of the board, so that the upper edge may be *a-wash*, or on a level with the surface of the water. If the dip should be less than this, part of the engine's

power would be ineffective in producing the motion of the ship; if greater, part of that power would be spent in overcoming the greater resistance experienced in alternately depressing and raising the water about the entering and emerging boards.

16. The diameters of paddle-wheels should not exceed four and a half times the length of stroke, for this reason, that if more, the "slip"[a] of the paddle will be great. With a wheel of such proportion the "slip" would be about 20 per cent. The inner edge of the paddle-board should have as nearly as possible the speed of the ship: the slip will then be at a minimum.

17. The length of a paddle-board should be about, or rather more than $\frac{1}{3}$ the diameter of the wheel. When the diameters of the wheels exceed $4\frac{1}{2}$ times the length of stroke, the engines ordinarily constructed are not capable of driving them effectively, so that the power of the engine is not fully developed. This power should correspond to the velocity assigned to the piston, suppose 200 or 220 feet per minute; and, to be enabled to obtain this with a larger wheel the paddle-board must be narrowed, which would augment the slip, and under adverse circumstances this might become very considerable.

18. These are the proportions for sea-going vessels, and the whole power of the engine should be effective when the vessel is at the mean draught of water, viz. the mean between her extreme light, and load-lines. In river vessels, perhaps, a diameter of wheel equal to about four times the length of stroke would be a good proportion. It is evident that the paddle-boards of sea-going vessels should be more deeply immersed than those of vessels which navigate a river, since at sea, on account of the vessel's pitches, the boards are great part of the time out of water.

19. From the known dimensions of the paddle-wheels in several vessels of war, it appears that the diameters of the wheels vary nearly with the square root of the

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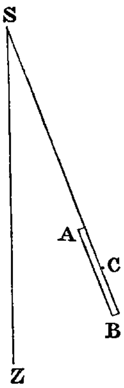
[a] Loss of power caused by the recession of the water *aftward* from the paddle-boards.

horse-power of the engine; and, with a vessel whose engine has a power equal to 200 horses, the diameter of the wheel, between the outer extremities of the paddle-boards, is about 20 feet; the lengths of the paddles are rather less than half, and the breadths between one-ninth and one-tenth of the diameter. Hence, if the circumference of a wheel 20 feet in diameter be furnished with 20 paddle-boards 2 feet broad, when the upper edge of the lowest vertical board is a-wash, there will be three boards wholly or partly immersed, one will be nearly entering the surface of the water, and a fifth will have just emerged from it.

20. If a vessel be retained at rest in still water while the wheels revolve, the reaction of the water against a paddle-board will be the greatest when the board is in a vertical position in the water, but this will not always be the case when the vessel is free to move by the rotation of the wheel. In order to explain this subject, let S be the centre of the wheel's rotation, and A B the momentary position of a paddle making, with the vertical line S Z, an angle Z S B represented by θ. Let V be the velocity of the point C (supposed to be the centre of pressure on A B) in a direction perpendicular to the surface of the paddle A B, and V′ the velocity of the vessel in the water, in a horizontal direction; then, by the Resolution of Forces or Velocities, V cos. θ is that velocity in a direction perpendicular to the surface of the paddle A B; therefore $V - V' \cos. \theta$ will express the relative velocity of the paddle and vessel in the same direction. But the resistance of a fluid against a body moving in it varies with the square of the velocity;[a] therefore $(V - V' \cos. \theta)^2$ may denote the force of resistance, or pressure, against the paddle: this being multiplied by V, the product is the efficient

Fig. 1.



[a] Experiments have shown that this rule is very nearly correct notwithstanding the perturbation of the water by the wheel's rotation.

momentum of that resistance in a direction perpendicular to the surface of the paddle ; and consequently

$$(V - V' \cos. \theta)^2 V \cos. \theta$$

is the efficient force by which that resistance impels the vessel forward horizontally : which, for the vertical paddle, where $\theta = 0$, becomes

$$(V - V')^2 V.$$

21. But in these expressions it is supposed that the paddles are wholly immersed : this is evidently not the case with the oblique paddles when the upper edge of the lowest vertical paddle is on a level with the surface of the water, for then the immersed part of an oblique paddle is expressed by S B — S A sec. θ; or, r being the radius of the wheel to the outer extremity of a paddle-board, and a the difference between r and the breadth (b) of the paddle, it is expressed by $r - a$ sec. θ : consequently the ratio between the efficient resistances against a vertical and an oblique paddle will be as

$$(V - V')^2 b\, V \ : \ (V - V' \cos. \theta)^2 V (r \cos. \theta - a).$$

These expressions being put in numbers according to the data, for different values of θ, it will be found that the first will be less than the second till the part of the paddle's breadth which is out of the water causes a diminution of power which more than compensates for the superiority which is due to the obliquity.

Making the differential of this last expression equal to zero, we may obtain the value of θ which makes the resistance a maximum. Assuming $V' = \frac{4}{5} V$, $r = 10$ feet, $a = 8$ feet, whence $b = 2$ feet, the greatest resistance takes place when $\theta = 18°$; and the force on the vertical paddle is, to that on the oblique paddle in this position, as 10 to 10·865.

The resistance against a vertical paddle being thus proved to be less than the resistance against an oblique paddle, in the most effective part of the motion of the latter, it follows that to obtain equal speed for two vessels, one of which is furnished with paddles of the ordinary kind, and the other with such as are kept by