CHAPTER IX.

STEAM NAVIGATION.

RESISTANCE OF VESSELS IN WATER.

533. *Q.*—How do you determine the resistance encountered by a vessel moving in water?

A.—The resistance experienced by vessels moving in water varies as the square of the velocity of their motion, or nearly so; and the power necessary to impart an increased velocity varies nearly as the cube of such increased velocity. To double the velocity of a steam vessel, therefore, will require four times the amount of tractive force, and as that quadrupled force must act through twice the distance in the same time, an engine capable of exerting eight times the original power will be required.*

534. *Q.*—In the case of a board moving in water in the manner of a paddle float, or in the case of moving water impinging on a stationary board, what will be the pressure produced by the impact?

---

* This statement supposes that there is no difference of level between the water at the bow and the water at the stern. In the experiments on the steamer Pelican, the resistance was found to vary, as the 2.28th power of the velocity, but the deviation from the recognized law was imputed to a difference in the level of the water at the bow and stern.

A.—The pressure produced upon a flat board, by striking water at right angles to the surface of the board, will be equal to the weight of a column of water having the surface struck as a base, and for its altitude twice the height due to the velocity with which the board moves through the water. If the board strike the water obliquely, the resistance will be less, but no very reliable law has yet been discovered to determine its amount.

535. *Q.*—Will not the resistance of a vessel in moving through the water be much less than that of a flat board of the area of the cross section?

A.—It will be very much less, as is manifest from the comparatively small area of paddle board, and the small area of the circle described by the screw, relatively with the area of the immersed midship section of the vessel. The absolute speed of a vessel, with any given amount of power, will depend very much upon her shape.

536. *Q.*—In what way is it that the shape of a vessel influences her speed, since the vessels of the same sectional area must manifestly put in motion a column of water of the same magnitude, and with the same velocity?

A.—A vessel will not strike the water with the same velocity when the bow lines are sharp as when they are otherwise; for a very sharp bow has the effect of enabling the vessel to move through a great distance, while the particles of water are moved aside but a small distance, or in other words, it causes the velocity with which the water is moved to be very small relatively with the velocity of the vessel; and as the resistance increases as the square of the velocity with which the water is moved, it is conceivable enough in what way a sharp bow may diminish the resistance.

537. *Q.*—Is the whole power expended in the propulsion of a vessel consumed in moving aside the water to enable the vessel to pass?

A.—By no means; only a portion, and in well-formed vessels only a small portion, of the power is thus consumed. In the majority of cases, the greater part of the power is expended in overcoming the friction of the water upon the bottom of the vessel; and the problem chiefly claiming consideration is, in what way we may diminish the friction.

538. *Q.*—Does the resistance produced by this friction increase with the velocity?

A.—It increases nearly as the square of the velocity. At two nautical miles per hour, the thrust necessary to overcome the friction varies as the 1·823 power of the velocity; and at eight nautical miles per hour, the thrust necessary to overcome the friction varies as the 1·713 power of the velocity. It is hardly proper, perhaps, to call this resistance by the name of friction; it is partly, perhaps mainly, due to the viscidity or adhesion of the water.

539. *Q.*—Perhaps at high velocities this resistance may become less?

A.—That appears very probable. It may happen that at high velocities the adhesion is overcome, so that the water is dragged off the vessel, and the friction thereafter follows the law which obtains in the case of solid bodies. But any such conclusion is mere speculation, since no experiments illustrative of this question have yet been made.

540. *Q.*—Will a vessel experience more resistance in moving in salt water than in moving in fresh?

A.—If the immersion be the same in both cases a vessel will experience more resistance in moving in salt water than in moving in fresh, on account of the greater density of salt water; but as the flotation is proportionably greater in the salt water the resistance will be the same with the same weight carried.

541. *Q.*—Discarding for the present the subject of friction, and looking merely to the question of bow and stern resistance, in what manner should the hull of a vessel be formed so as to make these resistances a minimum?

A.—The hull should be so formed that the water, instead of being away driven forcibly from the bow, is opened gradually, so that every particle of water may be moved aside slowly at first, and then faster, like the ball of a pendulum, until it reaches the position of the midship frame, at which point it will have come to a state of rest, and then again, like a returning pendulum, vibrate back in the same way, until it comes to rest at the stern. It is not difficult to describe mechanically the line which the water should pursue. If an endless web of paper be put into uniform motion, and a pendulum carrying a pencil or brush be hung in front of it, then such pendulum will trace on the paper the proper water line of the ship, or the line which the water should pursue in order that no power may be lost except that which is lost in friction. It is found, however, in practice, that vessels formed with water lines on this principle are not much superior to ordinary vessels in the facility with which they pass through the water: and this points to the conclusion that in ordinary vessels of good form, the amount of power consumed in overcoming the resistance due to the wave at the bow and the partial vacuity at the stern is not so great as has heretofore been supposed, and that, in fact, the main resistance is that due to the friction.

EXPERIMENTS ON THE RESISTANCE OF VESSELS.

542. *Q.*—Have experiments been made to determine the resistance which steam vessels experience in moving through the waters?

A.—Experiments have been made both to determine the relative resistance of different classes of vessels, and also the absolute resistance in pounds or tons. The first experiments made upon this subject were conducted by Messrs. Boulton and Watt, and they have been numerous, long continued, and carefully performed. These experiments were made upon paddle vessels.

543. *Q.*—Will you recount the chief results of these experiments?

A.—The purpose of the experiments was to establish a coefficient of performance, which with any given class of vessel would enable the speed, which would be obtained with any given power, to be readily predicted. This coefficient was obtained by multiplying the cube of the velocity of the vessels experimented upon, in miles per hour, by the sectional area of the immersed midship section in square feet, and dividing by the numbers of nominal horses power, and this coefficient will be large in the proportion of the goodness of the shape of the vessel.

544. *Q.*—How many experiments were made altogether?

A.—There were five different sets of experiments on five different classes of vessels. The first set of experiments was made in 1828, upon the vessels Caledonia, Diana, Eclipse, Kingshead, Moordyke, and Eagle—vessels of a similar form and all with square bilges and flat floors; and the result was to establish the number 925 as the coefficient of performance of such vessels. The second set of experiments was made upon the superior vessels Venus, Swiftsure, Dasher, Arrow, Spitfire, Fury, Albion, Queen, Dart, Hawk, Margaret, and Hero—all vessels having flat floors and round bilges, where the coefficient became 1160. The third set of experiments was made upon the vessels Lightning, Meteor, James Watt, Cinderella, Navy Meteor, Crocodile, Watersprite, Thetis, Dolphin, Wizard, Escape, and Dragon—all vessels with rising floors and round bilges, and the coefficient of performance was found to be 1430. The fourth set of experiments was made in 1834, upon the vessels Magnet, Dart, Eclipse, Flamer, Firefly, Ferret, and Monarch, when the coefficient of performance was found to be 1580. The fifth set of experiments was made upon the Red Rover, City of Canterbury, Herne, Queen, and Prince of Wales, and in the case of those vessels the coefficient rose to 2550. The velocity of any of these vessels, with any power or sectional area, may be ascertained by multiplying the coefficient of its class by the nominal horse power, dividing by the sectional area in square feet, and extracting the cube root of the quotient, which will be the velocity in miles per hour; or the number of nominal horse power requisite for the accomplishment of any required speed may be ascertained by multiplying the cube of the required velocity in miles per hour, by the sectional area in square feet, and dividing by the coefficient: the quotient is the number of nominal horse power requisite to realize the speed.

545. *Q.*—Seeing, however, that the nominal power does not represent an invariable amount of dynamical efficiency, would it

not be better to make the comparison with reference to the actual power?

A.—In the whole of the experiments recited, except in the case of one or two of the last, the pressure of steam in the boiler varied between 2¾ lbs. and 4 lbs. per square inch, and the effective pressure on the piston varied between 11 lbs. and 13 lbs. per square inch, so that the average ratio of the nominal to the actual power may be easily computed; but it will be preferable to state the nominal power of some of the vessels, and their actual power as ascertained by experiment.

546. *Q.*—Then state this.

A.—Of the Eclipse, the nominal power was 76, and the actual power 144·4 horses; of the Arrow, the nominal power was 60, and the actual 119·5; Spitfire, nominal 40, actual 64; Fury, nominal 40, actual 65·6; Albion, nominal 80, actual 135·4; Dart, nominal 100, actual 152·4; Hawk, nominal 40, actual 73; Hero, nominal 100, actual 171·4; Meteor, nominal 100, actual 160; James Watt, nominal 120, actual 204; Watersprite, nominal 76, actual 157·6; Dolphin, nominal 140, actual 238; Dragon, nominal 80, actual 131; Magnet, nominal 140, actual 238; Dart, nominal 120, actual 237; Flamer, nominal 120, actual 234; Firefly, nominal 52, actual 86·6; Ferret, nominal 52, actual 88; Monarch, nominal 200, actual 378. In the case of swift vessels of modern construction, such as the Red Rover, Herne, Queen, and Prince of Wales, the coefficient appears to be about 2550; but in these vessels there is a still greater excess of the actual over the nominal power than in the case of the vessels previously enumerated, and the increase in the coefficient is consequent upon the increased pressure of the steam in the boiler, as well as the superior form of the ship. The nominal power of the Red Rover, Herne, and City of Canterbury is, in each case, 120 horses, but the actual power of the Red Rover is 294, of the Herne 354, and of the City of Canterbury 306, and in some vessels the excess is still greater; so that with such variations it becomes necessary to adopt a coefficient derived from the introduction of the actual instead of the nominal power.

547. *Q.*—What will be the average difference between the nominal and actual powers in the several classes of vessels you have mentioned and the respective coefficients when corrected for the actual power?

A.—In the first class of vessels experimented upon, the actual power was about 1·6 times greater than the nominal power; in the second class, 1·67 times greater; in the third class, 1·7 times greater; and in the fourth, 1·96 times greater; while in such vessels as the Red Rover and City of Canterbury, it is 2·65 times greater; so that if we adopt the actual instead of the nominal power in fixing the coefficients, we shall have 554 as the first coefficient, 694 as the second, 832 for the third, and 806 for the fourth, instead of 925, 1160, 1430, and 1580 as previously specified; while for such vessels as the Red Rover, Herne, Queen, and Prince of Wales, we shall have 962 instead of 2550. These smaller coefficients, then, express the relative merits of the different vessels without reference to any difference of efficacy in the engines, and it appears preferable, with such a variable excess of the actual over the nominal power, to employ them instead of those first referred to. From the circumstance of the third of the new coefficients being greater than the fourth, it appears that the superior result in the fourth set of experiments arose altogether from a greater excess of the actual over the nominal power.

548. *Q.*—These experiments, you have already stated, were all made on paddle vessels. Have similar coefficients of performance been obtained in the case of screw vessels?

A.—The coefficients of a greater number of screw vessels have been obtained and recorded, but it would occupy too much time to enumerate them here. The coefficient of performance of the Fairy is 464·8; of the Rattler 676·8; and of the Frankfort 792·3. This coefficient, however, refers to nautical and not to statute miles. If reduced to statute miles for the purpose of comparison with the previous experiments, the coefficients will respectively become 703, 1033, and 1212; which indicate that the performance of screw vessels is equal to the performance of paddle vessels, but some of the superiority of the result may be imputed to the superior size of the screw vessels.

INFLUENCE OF THE SIZE OF VESSELS UPON THEIR SPEED.

549. *Q.*—Will large vessels attain a greater speed than small, supposing each to be furnished with the same proportionate power?

A.—It is well known that large vessels furnished with the same proportionate power, will attain a greater speed than small vessels, as appears from the rule usual in yacht races of allowing a certain part of the distance to be run to vessels which are of inferior size. The velocity attained by a large vessel will be greater than the velocity attained by a small vessel of the same mould and the same proportionate power, in the proportion of the square roots of the linear dimensions of the vessels. A vessel therefore with four times the sectional area and four times the power of a smaller symmetrical vessel, and consequently of twice the length, will have its speed increased in the proportion of the square root of 1 to the square root of 2, or 1·4 times.

550. *Q.*—Will you further illustrate this doctrine by an example?

A.—The screw steamer Fairy, if enlarged to three times the size while retaining the same form, would have twenty-seven times the capacity, nine times the sectional area, and nine times the power. The length of such a vessel would be 434 feet; her breadth 63 feet 4½ inches; her draught of water 16½ feet; her area of immersed section 729 square feet; and her nominal power 1080 horses. Now as the lengths of the Fairy and of the new vessel are in the proportion of 1 to 3, the speeds will be in the proportion of the square root of 1 to the square root of 3; or, in other words, the speed of the large vessel will be 1·73 times greater than the speed of the small vessel. If therefore the speed of the Fairy be 13 knots, the speed of the new vessel will be 22·49 knots, although the proportion of power to sectional area, which is supposed to be the measure of the resistance, is in both cases precisely the same. If the speed of the Fairy herself had to be increased to 22·29 knots, the power would have to be increased in the proportion of the cube of 13 to the cube of 22·49, or 5·2 times, which makes the power necessary to propel the Fairy at that speed equal to 624 nominal horses power.

STRUCTURE AND OPERATION OF PADDLE WHEELS.

551. *Q.*—Will you describe the configuration and mode of action of the paddle wheels in general use?

A.—There are two kinds of paddle wheels in extensive use, the one being the ordinary radial wheel, in which the floats are fixed on arms radiating from the centre; and the other the feathering wheel, in which each float is hung upon a centre, and is so governed by suitable mechanism as to be always kept in nearly the vertical position. In the radial wheel there is some loss of power from oblique action, whereas in the feathering wheel there is little or no loss from this cause; but in every kind of paddle there is a loss of power from the recession of the water from the float boards, or the *slip* as it is commonly called; and this loss is the necessary condition of the resistance for the propulsion of the vessel being created in a fluid. The slip is expressed by the difference between the speed of the wheel and the speed of the vessel, and the larger this difference is the greater the loss of power from slip must be—the consumption of steam in the engine being proportionate to the velocity of the wheel, and the useful effect being proportionate to the speed of the ship.

552. *Q.*—The resistance necessary for propulsion will not be situated at the circumference of the wheel?

A.—In the feathering wheel, where every part of any one immerged float moves forward with the same horizontal velocity, the pressure or resistance may be supposed to be concentrated in the centre of the float; whereas, in the common radial wheel this cannot be the case, for as the outer edge of the float moves more rapidly than the edge nearest the centre of the wheel, the outer part of the float is the most effectual in propulsion. The point at which the outer and inner portions of the float just balance one another in propelling effect, is called the *centre of pressure;* and if all the resistances were concentrated in this point, they would have the same effect as before in resisting the rotation of the wheel. The resistance upon any one moving float board totally immersed in the water will, when the vessel is at rest, obviously vary as the square of its distance from the centre of motion—the resistance of a fluid varying with the square of the velocity; but, except when the wheel is sunk to the axle or altogether immersed in the water, it is impossible, under ordinary circumstances, for one float to be totally immersed without others being immersed partially, whereby the arc described by the extremity of the paddle arm will become greater than the arc described by the inner edge of the float; and consequently the resistance upon any part of the float will increase in a higher ratio than the square of its distance from the centre of motion—the position of the centre of pressure being at the same time correspondingly affected. In the feathering wheel the position of the centre of pressure of the entering and emerging floats is continually changing from the lower edge of the float—where it is when the float is entering or leaving the water—to the centre of the float, which is its position when the float is wholly immerged; but in the radial wheel the centre of pressure can never rise so high as the centre of the float.

553. *Q.*—All this relates to the action of the paddle when the vessel is at rest: will you explain its action when the vessel is in motion?

A.—When the wheel of a coach rolls along the ground, any point of its periphery describes in the air a curve which is termed a cycloid; any point within the periphery traces a prolate or protracted cycloid, and any point exterior to the periphery traces a curtate or contracted cycloid—the prolate cycloid partaking more of the nature of a straight line, and the curtate cycloid more of the nature of a circle. The action of a paddle wheel in the water resembles in this respect that of the wheel of a carriage running along the ground: that point in the radius of the paddle of which the rotative speed is just equal to the velocity of the vessel will describe a cycloid; points nearer the centre, prolate cycloids, and points further from the centre, curtate cycloids. The circle described by the point whose velocity equals the velocity of the ship, is called the *rolling circle*, and the resistance due to the difference of velocity of the rolling circle and centre of pressure is that which operates in the propulsion of the vessel. The resistance upon any part of the float, therefore, will vary as the square of its distance from the rolling circle, supposing the float to be totally immerged; but, taking into account the greater length of time during which the extremity of the paddle acts, whereby the resistance will be made greater, we shall not err far in estimating the resistance upon any point at the third power of its distance from the rolling circle in the case of light immersions, and the 2·5 power in the case of deep immersions.

554. *Q.*—How is the position of the centre of pressure to be determined?

A.—With the foregoing assumption, which accords sufficiently with experiment to justify its acceptation, the position of the centre of pressure may be found by the following rule:—from the radius of the wheel substract the radius of the rolling circle; to the remainder add the depth of the paddle board, and divide the fourth power of the sum by four times the depth; from the cube root of the quotient subtract the difference between the radii of the wheel and rolling circle, and the remainder will be the distance of the centre of pressure from the upper edge of the paddle.

555. *Q.*—How do you find the diameter of the rolling circle?

A.—The diameter of the rolling circle is very easily found, for we have only to divide 5,280 times the number of miles per hour, by 60 times the number of strokes per minute, to get an expression for the circumference of the rolling circle, or the following rule may be adopted:—divide 88 times the speed of the vessel in statute miles per hour, by 3·1416 times the number of strokes per minute; the quotient will be the diameter in feet of the rolling circle. The diameter of the circle in which the centre of pressure moves or the effective diameter of the wheel being known, and also the diameter of the rolling circle, we at once find the excess of the velocity of the wheel over the vessel.

556. *Q.*—Will you illustrate these rules by an example?

A.—A steam vessel of moderately good shape, and with engines of 200 horses power, realises, with 22 strokes per minute, a speed of 10·62 miles per hour. To find the diameter of the rolling circle, we have 88 times 10·62, equal to 934·66, and 22 times 3·1416, equal to 69·1152; then 934·66 divided by 69·1152 is equal to 13·52 feet, which is the diameter of the rolling circle. The diameter of the wheel is 19 ft. 4 in., so that the diameter of the rolling circle is about $\frac{2}{3}$ds of the diameter of the wheel, and this is a frequent proportion. The depth of the paddle board is 2 feet, and the difference between the diameters of the wheel and rolling circle will be 5·8133, which will make the difference of their radii 2·9067; and adding to this the depth of the paddle board, we have 4·9067, the fourth power of which is 579·64, which, divided by four times the depth of the paddle board, gives us 72·455, the cube root of which is 4·1689, which, diminished by the difference of the radii of the wheel and rolling circle, leaves 1·2622 feet for the distance of the centre of pressure from the upper edge of the paddle board in the case of light immersions. The radius of the wheel being 9·6667, the distance from the centre of the wheel to the upper edge of the float is 7·6667, and adding to this 1·2622, we get 8·9299 feet as the radius, or 17·8598 feet as the diameter of the circle in which the centre of pressure revolves. With 22 strokes per minute, the velocity of the centre of pressure will be 20·573 feet per second, and with 10·62 miles per hour for the speed of the vessel, the velocity of the rolling circle will be 15·576 feet per second. The effective velocity will be the difference between these quantities, or 4·997 feet per second. Now the height from which a body must fall by gravity, to acquire a velocity of 4·997 feet per second, is about ·62 feet; and twice this height, or 1·24 feet, multiplied by 62½, which is the number of lbs. weight in a cubic foot of water, gives 77½ lbs. as the pressure on each square foot of the vertical paddle boards. As each board is of 20 square feet of area, and there is a vertical board on each side of the ship, the total pressure on the vertical paddle boards will be 2900 lbs.

557. *Q.*—What pressure is this equivalent to on each square inch of the pistons?

A.—A vessel of 200 horses power will have two cylinders, each 50 inches diameter, and 5 feet stroke, or thereabout. The area of a piston of 50 inches diameter is 1963·5 square inches, so that the area of the two pistons is 3927 square inches, and the piston will move through 10 feet every revolution; and with 22 strokes per minute this will be 220 feet per minute, or 3·66 feet per second. Now, if the effective velocity of the centre of pressure and the velocity of the pistons had been the same, then a pressure of 2900 lbs. upon the vertical paddles would have been balanced by an equal pressure on the pistons, which would have been in this case about ·75 lbs. per square inch; but as the effective velocity of the centre of pressure is 4·997 feet per second, while that of the pistons is only 3·66 feet per second, the pressure must be increased in the proportion of 4·997 to 3·66 to establish an equilibrium of pressure, or, in other words, it must be 1·02 lbs. per square inch. It follows from this investigation, that, in radial wheels, the greater part of the engine power is distributed among the oblique floats.

558. *Q.*—How comes this to be the case?

A.—To understand how it happens that more power is expended upon the oblique than upon the vertical floats, it is necessary to remember that the only resistance upon the vertical paddle is that due to the difference of velocity of the wheel and the ship; but if the wheel be supposed to be immersed to its axle, so that the entering float strikes the water horizontally, it is clear that the resistance on such float is that due to the whole velocity of rotation; and that the resistance to the entering float will be the same whether the vessel is in motion or not. The resistance opposed to the rotation of any float increases from the position of the vertical float—where the resistance is that due to the difference of velocity of the wheel and vessel—until it reaches the plane of the axis, supposing the wheel to be immersed so far, where the resistance is that due to the whole velocity of rotation; and although in any oblique float the total resistance cannot be considered operative in a horizontal direction, yet the total resistance increases so rapidly on each side of the vertical float, that the portion of it which is operative in the horizontal direction, is in all ordinary cases of immersion very considerable. In the feathering wheel, where there is little of this oblique action, the resistance will be in the proportion of the square of the horizontal velocities of the several floats, which may be represented by the horizontal distances between them; and in the feathering wheel, the vertical float having the greatest horizontal velocity will have the greatest propelling effect.

559. *Q.*—Should the floats in feathering wheels enter and leave the water vertically?

A.—The floats should be so governed by the central crank or eccentric, that the entering and emerging floats have a direction intermediate between a radius and a vertical line.

560. *Q.*—Can you give any practical rules for proportioning paddle wheels?

A.—A common rule for the pitch of the floats is to allow one float for every foot of diameter of the wheel; but in the case of fast vessels a pitch of 2½ feet, or even less, appears preferable, as a close pitch occasions less vibration. If the floats be put too close, however, the water will not escape freely from between them, and if set too far apart the stroke of the entering paddle will occasion an inconvenient amount of vibratory motion, and there will also be some loss of power. To find the proper area of a single float:—divide the number of actual horses power of both engines by the diameter of the wheel in feet; the quotient is the area of one paddle board in square feet proper for sea going vessels, and the area multiplied by 0·6 will give the length of the float in feet. In very sharp vessels, which offer less resistance in passing through the water, the area of paddle board is usually one-fourth less than the above proportion, and the proper length of the float may in such case be found by multiplying the area by 0·7. In sea going vessels about four floats are usually immersed, and in river steamers only one or two floats. There is more slip in the latter case, but there is also more engine power exerted in the propulsion of the ship, from the greater speed of engine thus rendered possible.

561. *Q.*—Then is it beneficial to use small floats?

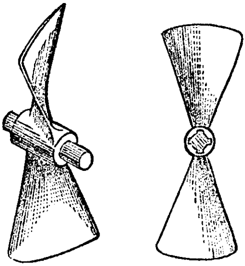
A.—Quite the contrary. If to permit a greater speed of the engine the floats be diminished in area instead of being raised out of the water, no appreciable accession to the speed of the vessel will be obtained; whereas there will be an increased speed of vessel if the accelerated speed of the engine be caused by diminishing the diameter of the wheels. In vessels intended to be fast, therefore, it is expedient to make the wheels small, so as to enable the engine to work with a high velocity; and it is expedient to make such wheels of the feathering kind, to obviate loss of power from oblique action. In no wheel must the rolling circle fall below the water line, else the entering and emerging floats will carry masses of water before them. The slip is usually equal to about one-fourth of the velocity of the centre of pressure in well proportioned wheels; but it is desirable to have the slip as small as is possible consistently with the observance of other necessary conditions. The speed of the engine and also the speed of the vessel being fixed, the diameter of the rolling circle becomes at once ascertainable, and adding to this the slip, we have the diameter of the wheel.

CONFIGURATION AND ACTION OF THE SCREW.

562. *Q.*—Will you describe more in detail than you have yet done, the configuration and mode of action of the screw propeller?

A.—The ordinary form of screw propeller is represented in *figs.* 46 and 47; *fig.* 46 being a perspective view, and *fig.* 47 an end view, or view such as is seen when looking upon the end of the shaft. The screw here represented is one with two arms or blades. Some screws have three arms, some four and some six; but the screw with two arms is the most usual, and screws with more than three arms are not now much employed in this country. The screw on being put into revolution by the engine, preserves a spiral path in the water, in which it draws itself forward in the same way as a screw nail does when turned round in a piece of wood, whereas the paddle wheel more resembles the action of a cog wheel working in a rack.

Fig. 46. Fig. 47.



ORDINARY FORM OF SCREW PROPELLER.

563. *Q.*—But the screw of a steam vessel has no resemblance to a screw nail?

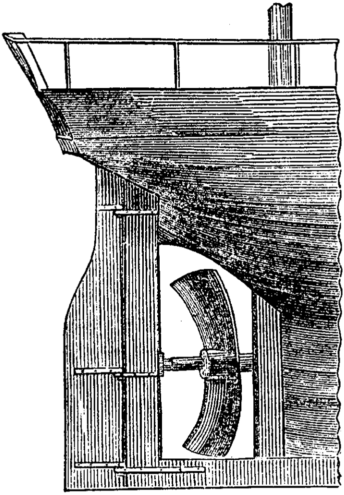
A.—It has in fact a very close resemblance if you suppose only a very short piece of the screw nail to be employed, and if you suppose, moreover, the thread of the screw to be cut nearly into the centre to prevent the wood from stripping. The original screw propellers were made with several convolutions of screw, but it was found advantageous to shorten them, until they are now only made one-sixth of a convolution in length.

564. *Q.*—And the pitch you have already explained to be the distance in the line of the shaft from one convolution to the next, supposing the screw to consist of two or more convolutions?

A.—Yes, that is what is meant by the pitch. If a thread be wound upon a cylinder with an equal distance between the convolutions, it will trace a screw of a uniform pitch; and if the thread be wound upon the cylinder with an increasing distance between each convolution, it will trace a screw of an increasing pitch. But two or more threads may be wound upon the cylinder at the same time, instead of a single thread. If two threads be wound upon it they will trace a double-threaded screw; if three threads be wound upon it they will trace a treble-threaded screw; and so of any other number. Now if the thread be supposed to be raised up into a very deep and thin spiral feather, and the cylinder be supposed to become very small, like the newel of a spiral stair, then a screw will be obtained of the kind proper for propelling vessels, except that only a very short piece of such screw must be employed. Whatever be the number of threads wound upon a cylinder, if the cylinder be cut across all the threads will be cut. A slice cut out of the cylinder will therefore contain a piece of each thread. But the threads, in the case of a screw propeller, answer to the arms, so that in every screw propeller the number of threads entering into the composition of the screw will be the same as the number of arms. An ordinary screw with two blades is a short piece of a screw of two threads.

565. *Q.*—In what part of the ship is the screw usually placed?

Fig. 48.



A.—In that part of the run of the ship called the dead wood, which is a thin and unused part of the vessel just in advance of the rudder. The usual arrangement is shown in *fig.* 48, which represents the application to a vessel of a species of screw which has the arms bent backwards, to counteract the centrifugal motion given to the water when there is a considerable amount of slip.

566. *Q.*—How is the slip in a screw vessel determined?

A.—By comparing the actual speed of the vessel with the speed due to the pitch and number of revolutions of the screw, or, what is the same thing, the speed which the vessel would attain if the screw worked in a solid nut. The difference between the actual speed and this hypothetical speed, is the slip.

567. *Q.*—In well formed screw propellers what is the amount of slip found to be?

A.—If the screw be properly proportioned to the resistance that the vessel has to overcome, the slip will not be more than 10 per cent., but in some cases it amounts to 30 per cent., or even more than this. In other cases, however, the slip is nothing at all, and even less than nothing; or, in other words the vessel passes through the water with a greater velocity than if the screw were working in a solid nut.

568. *Q.*—Then it must be by the aid of the wind or some other extraneous force?

A.—No; by the action of the screw alone.

569. *Q.*—But how is such a result possible?

A.—It appears to be mainly owing to the centrifugal action of the screw, which interposes a film or wedge of water between the screw itself and the water on which the screw reacts. This negative slip, as it is called, chiefly occurs when the pitch of the screw is less than its diameter, and when, consequently, the velocity of rotation is greater than if a coarser pitch had been employed. There is, moreover, in all vessels passing through the water with any considerable velocity, a current of water following the vessel, in which current, in the case of a screw vessel, the screw will revolve; and in certain cases the phenomenon of negative slip may be imputable in part to the existence of this current.

570. *Q.*—Is the screw propeller as effectual an instrument of propulsion as the radial or feathering paddle?

A.—In all cases of deep immersion it appears to be quite as effectual as the radial paddle, indeed, more so; but it is scarcely as effectual as the feathering paddle, with any amount of immersion, and scarcely as effectual as the common paddle in the case of light immersions.

COMPARATIVE ADVANTAGES OF PADDLE AND SCREW VESSELS.

571. *Q.*—Whether do you consider paddle or screw vessels to be on the whole the most advantageous?

A.—That is a large question, and can only receive a qualified answer. In some cases the use of paddles is indispensable, as, for example, in the case of river vessels of a limited draught of water, where it would not be possible to get sufficient depth below the water surface to enable a screw of a proper diameter to be got in.

572. *Q.*—But how does the matter stand in the case of ocean vessels?

A.—In the case of ocean vessels, it is found that paddle vessels fitted with the ordinary radial wheels, and screw vessels fitted with the ordinary screw, are about equally efficient in calms and in fair or beam winds with light and medium immersions. If the vessels are loaded deeply, however, as vessels starting on a long voyage and carrying much coal must almost necessarily be, then the screw has an advantage, since the screw acts in its best manner when deeply immersed, and the paddles in their worst. When a screw and paddle vessel, however, of the same model and power are set to encounter head winds, the paddle vessel it is found has in all cases an advantage, not in speed, but in economy of fuel. For whereas in a paddle vessel, when her progress is resisted, the speed of the engine diminishes nearly in the proportion of the diminished speed of ship, it happens that in a screw vessel this is not so,—at least to an equal extent, —but the engines work with nearly the same rate of speed as if no increase of resistance had been encountered by the ship. It follows from this circumstance, that whereas in paddle vessels the consumption of steam, and therefore of fuel, per hour is materially diminished when head winds occur, in screw vessels a similar diminution in the consumption of steam and fuel does not take place.

573. *Q.*—But perhaps under such circumstances the speed of the screw vessel will be the greater of the two?

A.—No; the speed of the two vessels will be the same, unless the strength of the head wind be so great as to bring the vessels nearly to a state of rest, and on that supposition the screw vessel will have the advantage. Such cases occur very rarely in practice; and in the case of the ordinary resistances imposed by head winds, the speed of the screw and paddle vessel will be the same, but the screw vessel will consume most coals.

574. *Q.*—What is the cause of this peculiarity?

A.—The cause is, that when the screw is so proportioned in its length as to be most suitable for propelling vessels in calms, it is too short to be suitable for propelling vessels which encounter a very heavy resistance. It follows, therefore, that if it is prevented from pursuing its spiral course in the water, it will displace the water to a certain extent laterally, in the manner it does if the engine be set on when the vessel is at anchor; and a part of the engine power is thus wasted in producing a useless disturbance of the water, which in paddle vessels is not expended at all.

575. *Q.*—If a screw and paddle vessel of the same mould and power be tied stern to stern, will not the screw vessel preponderate and tow the paddle vessel astern against the whole force of her engines?

A.—Yes, that will be so.

576. *Q.*—And seeing that the vessels are of the same mould and power, so that neither can derive an advantage from a variation in that condition, does not the preponderance of the screw vessel show that the screw must be the most powerful propeller?

A.—No, it does not.

577. *Q.*—Seeing that the vessels are the same in all respects except as regards the propellers, and that one of them exhibits a superiority, does not this circumstance show that one propeller must be more powerful than the other?

A.—That does not follow necessarily, nor is it the fact in this particular case. All steam vessels when set into motion, will force themselves forward with an amount of thrust which, setting aside the loss from friction and from other causes, will just balance the pressure on the pistons. In a paddle vessel, as has already been explained, it is easy to tell the tractive force exerted at the centre of pressure of the paddle wheels, when the pressure urging the pistons, the dimensions of the wheels and the speed of the vessel are known; and that force, whatever be its amount, must always continue the same with any constant pressure on the pistons. In a screw vessel the same law applies, so that with any given pressure on the pistons and discarding the consideration of friction, it will follow that whatever be the thrust exerted by a paddle or a screw vessel, it must remain uniform whether the vessel is in motion or at rest, and whether moving at a high or a low velocity through the water. Now to achieve an equal speed during calms in two vessels of the same model, there must be the same amount of propelling thrust in each; and this thrust, whatever be its amount, cannot afterward vary if a uniform pressure of steam be maintained. The thrusts, therefore, caused by their respective propelling instruments, when a screw and paddle vessel are tied stern to stern, must be the same as at other times; and as at other times those thrusts are equal, so must they be when the vessels are set in the antagonism supposed.

578. *Q.*—How comes it then that the screw vessel preponderates?

A.—Not by virtue of a larger thrust exerted by the screw in pressing forward the shaft and with it the vessel, but by the gravitation against the stern of the wave of water which the screw raises by its rapid rotation. This wave will only be raised very high when the progress of the vessel through the water is nearly arrested, at which time the centrifugal action of the screw is very great; and the vessel under such circumstances is forced forward partly by the thrust of the screw, and partly by the hydrostatic pressure of the protuberance of water which the centrifugal action of the screw raises up at the stern.

579. *Q.*—Can you state any facts in corroboration of this view?

A.—The screw vessel will not prepnoderate if a screw and paddle vessel be tied bow to bow and the engines of each be then reversed. In some screw vessels the amount of thrust actually exerted by the screw under all its varying circumstances, has been ascertained by the application of a dynamometer to the end of the shaft. By this instrument—which is formed by a combination of levers like a weighing machine for carts—a thrust or pressure of several tons can be measured by the application of a small weight; and it has been found, by repeated experiment with the dynamometer, that the thrust of the screw in a screw vessel when towing a paddle vessel against the whole force of her engines, is just the same as it is when the two vessels are maintaining an equal speed in calms. The preponderance of the screw vessel must, therefore, be imputable to some other agency than to a superior thrust of the screw, which is found by experiment not to exist.

580. *Q.*—Has the dynamometer been applied to paddle vessels?

A.—It has not been applied to the vessels themselves, as in the case of screw vessels, but it has been employed on shore to ascertain the amount of tractive force that a paddle vessel can exert on a rope.

581. *Q.*—Have any experiments been made to determine the comparative performances of screw and paddle vessels at sea?

A.—Yes, numerous experiments; of which the best known are probably those made on the screw steamer Rattler and the paddle steamer Alecto, each vessel of the same model, size, and power,—each vessel being of about 800 tons burden and 200 horses power. Subsequently another set of experiments with the same object was made with the Niger screw steamer and the Basilisk paddle steamer, both vessels being of about 1000 tons burden and 400 horses power. The general results which were obtained in the course of these experiments are those which have been already recited.

582. *Q.*—Will you recapitulate some of the main incidents of these trials?

A.—I may first state some of the chief dimensions of the vessels. The Rattler is 176 feet 6 inches long, 32 feet 8½ inches broad, 888 tons burden, 200 horses power, and has an area of immersed midship section of 380 square feet at a draught of water of 11 feet 5½ inches. The Alecto is of the same dimensions in every respect, except that she is only of 800 tons burden, the difference in this particular being wholly owing to the Rattler having been drawn out about 15 feet at the stern, to leave abundant room for the application of the screw. The Rattler was fitted with a dynamometer, which enabled the actual propelling thrust of the screw shaft to be measured; and the amount of this thrust, multiplied by the distance through which the vessel passed in a given time, would determine the amount of power actually utilized in propelling the ship. Both vessels were fitted with indicators applied to the cylinders, so as to determine the amount of power exerted by the engines.

583. *Q.*—How many trials of the vessels were made on this occasion?

A.—Twelve trials in all; but I need not refer to those in which similar or identical results were only repeated. The first trial was made under steam only, the weather was calm and the water smooth. At 54 minutes past 4 in the morning both vessels left the Nore, and at 30½ minutes past 2 the Rattler stopped her engines in Yarmouth Roads, where in 20½ minutes afterward she was joined by the Alecto. The mean speed achieved by the Rattler during this trial was 9·2 knots per hour; the mean speed of the Alecto was 8·8 knots per hour. The slip of the screw was 10·2 per cent. The actual power exerted by the engines, as shown by the indicator, was in the case of the Rattler 334·6 horses, and in the case of the Alecto 281·2 horses; being a difference of 53·4 horses in favor of the Rattler. The forward thrust upon the screw shaft was 3 tons, 17 cwt., 3 qrs., and 14 lbs. The horse power of the shaft—or power actually utilized—ascertained by multiplying the thrust in pounds by the space passed through by the vessel in feet per minute, and dividing by 33,000, was 247·8 horses power. This makes the ratio of the shaft to the engine power as 1 to 1·3, or, in other words, it shows that the amount of engine power utilized in propulsion was 77 per cent. In a subsequent trial made with the vessels running before the wind, but with no sails set and the masts struck, the speed realized by the Rattler was 10 knots per hour. The slip of the screw was 11·2 per cent. The actual power exerted by the engines of the Rattler was 368·8 horses. The actual power exerted by the engines of the Alecto was 291·7 horses. The thrust of the shaft was equal to a weight of 4 tons, 4 cwt., 1 qr., 1 lb. The horse power of the shaft was 290·2 horses, and the ratio of the shaft to the engine power was 1 to 1·2. Here, therefore, the amount of the engine power utilized was 84 per cent.

584. *Q.*—If in any screw vessel the power of the engine be diminished by shutting off the steam or otherwise, you will then have a larger screw relatively with the power of the engine than before ?

A.—Yes.

585. *Q.*—Was any experiment made to ascertain the effect of this modification ?

A.—There was; but the result was not found to be better than before. The experiment was made by shutting off the steam from the engines of the Rattler until the number of strokes was reduced to 17 in the minute. The actual power was then 126·7 horses; thrust upon the shaft 2 tons, 2 cwt., 3 qrs., 14 lbs; horse power of shaft 88·4 horses; ratio of shaft to engine power 1 to 1·4; slip of the screw 18·7 per cent. In this experiment the power utilized was 71 per cent.

586. *Q.*—Was any experiment made to determine the relative performances in head winds ?

A.—The trial in which this relation was best determined lasted for seven hours, and was made against a strong head wind and heavy head sea. The speed of the Rattler by patent log was 4·2 knots; and at the conclusion of the trial the Alecto had the advantage by about half a mile. Owing to an accidental injury to the indicator, the power exerted by the engines of the Rattler in this trial could not be ascertained; but judging from the power exerted in other experiments with the same number of revolutions, it appears probable that the power actually exerted by the Rattler was about 300 horses. The number of strokes per minute made by the engines of the Rattler was 22, whereas in the Alecto the number of strokes per minute was only 12; so that while the engines of the Alecto were reduced, by the resistance occasioned by a strong head wind, to nearly half their usual speed, the engines of the Rattler were only lessened about one twelfth of their usual speed. The mean thrust upon the screw shaft during this experiment, was 4 tons, 7 cwt., 0 qr., 16 lbs. The horse power of the shaft was 125·9 horses, and the slip of the screw was 56 per cent. Taking the power actually exerted by the Rattler at 300 horses, the power utilized in this experiment is only 42 per cent.

587. *Q.*—What are the dimensions of the screw in the Rattler?

A.—Diameter 10 feet, length 1 foot 3 inches, pitch 11 feet. The foregoing experiments show that with a larger screw a better average performance would be obtained. The best result arrived at, was when the vessel was somewhat assisted by the wind, which is equivalent to a reduction of the resistance of the hull, or to a smaller hull, which is only another expression for a larger proportionate screw.

588. *Q.*—When you speak of a larger screw, what increase of dimension do you mean to express?

A.—An increase of the diameter. The amount of reacting power of the screw upon the water is not measured by the number of square feet of surface of the arms, but by the area of the disc or circle in which the screw revolves. The diameter of the screw of the Rattler being 10 feet, the area of its disc is 78·5 square feet; and with the amount of thrust already mentioned as existing in the first experiment, viz. 8722 lbs., the reacting pressure on each square foot of the screw's disc will be 108½ lbs. The immersed midship section being 380 square feet, this is equivalent to 23 lbs. per square foot of immersed midship section at a speed of 9·2 knots per hour.

589. *Q.*—In smaller vessels of similar form, will the resistance per square foot of midship section be more than this?

A.—It will be considerably more. In the Pelican, a vessel of 109¾ square feet of midship section, I estimate the resistance per square foot of midship section at 30 lbs., when the speed of the vessel is 9·7 knots per hour. In the Minx with an immersed midship section of 82 square feet, the resistance per square foot of immersed midship section was found by the dynamometer to be 41 lbs. at a speed of 8½ knots; and in the Dwarf, a vessel with 60 square feet of midship section, I estimate the resistance per square foot of midship section at 46 lbs. at a speed of 9 knots per hour, which is just double the resistance per square foot of the Rattler. The diameter of the screw of the Minx is 4½ feet, so that the area of its disc is 15·9 square feet, and the area of immersed midship section is about 5 times greater than that of the screw's disc. The diameter of the screw of the Dwarf is 5 feet 8 inches, so that the area of its disc is 25·22 square feet, and the area of immersed midship section is 2·4 times greater than that of the screw's disc. The pressure per square foot of the screw's disc is 214 lbs. in the case of the Minx, and 109½ lbs. in the case of the Dwarf.

590. *Q.*—From the greater proportionate resistance of small vessels, will not they require larger proportionate screws than large vessels?

A.—They will.

591. *Q.*—Is there any ready means of predicting what the amount of thrust of a screw will be?

A.—When we know the amount of pressure on the pistons, and the velocity of their motion relatively with the velocity of advance made by the screw, supposing it to work in a solid nut, it is easy to tell what the thrust of the screw would be if it were cleared of the effects of friction and other irregular sources of disturbance. The thrust, in fact, would be at once found by the principle of virtual velocities; and if we take this theoretical thrust and diminish it by one fourth to compensate for friction and lateral slip, we shall have a near approximation to the amount of thrust that will be actually exerted.*

---

* See Treatise on the Screw Propeller, by J. Bourne, C. E.

COMPARATIVE ADVANTAGES OF DIFFERENT SCREWS.

592. *Q.*—What species of screw do you consider the best?

A.—In cases in which a large diameter of screw can be employed, the ordinary screw or helix with two blades seems to be as effective as any other, and it is the most easily constructed. If, however, the screw is restricted in diameter, or if the vessel is required to tow, or will have to encounter habitually strong head winds, it will be preferable to employ a screw with an increasing pitch, and also of such other configuration that it will recover from the water some portion of the power that has been expended in slip.

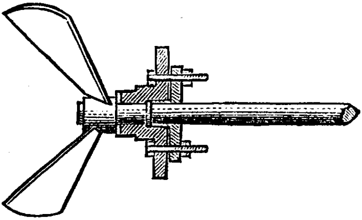
593. *Q.*—How can this be done?

A.—There are screws which are intended to accomplish this object already in actual use. When there is much slip a centrifugal velocity is given to the water, and the screw, indeed, if the engine be set on when the vessel is at rest, acts very much as a centrifugal fan would do if placed in the same situation. The water projected outward by the centrifugal force escapes in the line of least resistance, which is to the surface; and if there be a high column of water over the screw, or, in other words, if the screw is deeply immersed, then the centrifugal action is resisted to a greater extent, and there will be less slip produced. The easiest expedient, therefore, for obviating loss by slip is to sink the screw deeply in the water; but as there are obvious limits to the application of this remedy, the next best device is to recover and render available for propulsion some part of the power which has been expended in giving motion to the water. One device for doing this consists in placing the screw well forward in the dead wood, so that it shall be overhung by the stern of the ship. The water forced upward by the centrifugal action of the screw will, by impinging on the overhanging stern, press the vessel forward in the water, just in the same way as is done by the wind when acting on an oblique sail. I believe, the two revolving vanes without any twist or obliquity on them at all, would propel a vessel if set well forward in the dead wood or beneath the bottom, merely by the ascent of the water up the inclined plane of the vessel's run; and, at all events, a screw so placed would, in my judgment, aid materially in propelling the vessel when her progress was resisted by head winds.

594. *Q.*—But you said there are some kinds of screws which profess to accomplish this?

A.—There are screws which profess to counteract the centrifugal velocity given to the water by imparting to it an equal centripetal force, the consequence of which will be, that the water projected backward by the screw, instead of taking the form of the frustum of a cone, with its small end next the screw, will take the form of a cylinder. One of these forms of screw is that patented by the Earl of Dundonald in 1843, and which is represented in *fig.* 49. Another is the form of screw already represented in *fig.* 48, and which was patented by Mr. Hodgson in 1844. Mr. Hodgson bends the arms of his propellers backward, not into the form of a triangle, but into the form of a parabola, to the end that the impact of the screw on the particles of the water may cause them to converge to a focus, as the rays of light would do in a parabolic reflector. But this particular configuration is not important, seeing that the same convergence which is given to the particles of the water, with a screw of uniform pitch bent back into the form of a parabola, will be given with a screw bent back into the form of a triangle, if the pitch be suitably varied between the centre and the circumference.

Fig. 49.



THE EARL OF DUNDONALD'S PROPELLER.

595. *Q.*—Then the pitch may be varied in two ways?

A.—Yes: a screw may have a pitch increasing in the direction of the length, as would happen in the case of a spiral stair, if every successive step in the ascent was thicker than the one below it; or it may increase from the centre to the circumference, as would happen in the case of a spiral stair, if every step were thinner at the centre of the lower than at its outer wall. When the pitch of a screw increases in the direction of its length, the leading edge of the screw enters the water without shock or impact, as the advance of the leading edge per revolution will not be greater than the advance of the vessel. When the pitch of a screw increases in the direction of its diameter, the central part of the screw will advance with only the same velocity as the water, so that it cannot communicate any centrifugal velocity to the water; and the whole slip, as well as the whole propelling pressure, will occur at the outer part of the screw blades.

596. *Q.*—Is there any advantage derived from these forms of screws?

A.—There is a slight advantage, but it is so slight as hardly to balance the increased trouble of manufacture, and, consequently, they are not generally or widely adopted.

597. *Q.*—What other kinds of screw are there proposing to themselves the same or similar objects?

A.—There is the corrugated screw, the arms of which are corrugated, so as it were to gear with the water during its revolution, and thereby prevent it from acquiring a centrifugal velocity. Then there is Griffith's screw, which has a large ball at its centre, which, by the suction it creates at its hinder part, in passing through the water, produces a converging force, which partly counteracts the divergent action of the arms. Finally, there is Holm's screw, which has now been applied to a good number of vessels with success.

598. *Q.*—Will you describe the configuration and action of Holm's screw?

A.—First, then, the screw increases in the direction of its length, and this increase is very rapid at the following edge, so that, in fact, the following edge stands in the plane of the shaft, or in the vertical longitudinal plane of the vessel. Then the ends of the arms are bent over into a curved flange, the edge of which points astern, and the point where this curved flange joins the following edge of the screw is formed, not into an angle, but into a portion of a sphere, so that this corner resembles the bowl of a spoon. When the screw is put into revolution, the water is encountered by the leading edge of the screw without shock, as its advance is only equal to the advance of the vessel, and before the screw leaves the water it is projected directly astern. At the same time, the curved flange at the rim of the screw prevents the dispersion of the water in a radial direction, and it consequently assumes the form of a column or cylinder of water, projected backward from the ship.

599. *Q.*—What is the nature of Beattie's screw?

A.—Beattie's screw is an arrangement of the screw propeller whereby it is projected beyond the rudder, and the main object of the arrangement is to take away the vibratory motion at the stern,—an intention which it accomplishes in practice. There is an oval eye in the rudder, to permit the screw shaft to pass through it.

600. *Q.*—When the diameter of the cylinder of water projected backward by a screw, and the force urging it into motion are known, may not the velocity it will acquire be approximately determined?

A.—That will not be very difficult; and I will take for illustration the case of the Minx, already referred to, which will show how such a computation is to be conducted. The speed of this vessel, in one of the experiments made with her, was 8·445 knots; the number of revolutions of the screw per minute, 231·32; and the pressure on each square foot of area of the screw's disc, 214 lbs. If a knot be taken to be 6075·6 feet, then the distance advanced by the vessel, when the speed is 8·445 knots, will be 3·7 feet per revolution, and this advance will be made in about ·26 of a second of time. Now the distance which a body will fall by gravity, in ·26 of a second, is 1·087 feet; and a weight of 214 lbs. put into motion by gravity, or by a pressure of 214 lbs., would, therefore, acquire a velocity of

1·087 feet during the time one revolution of the screw is being performed. The weight to be moved, however, is 3·7 cubic feet of water, that being the new water seized by the screw each revolution for every square foot of surface in the screw's disc; and 3·7 cubic feet of water weigh 231·5 lbs., so that the urging force of 214 lbs. is somewhat less than the force of gravity, and the velocity of motion communicated to the water will be somewhat under 1·087 feet per revolution, or we may say it will be in round numbers 1 foot per revolution. This, added to the progress of the vessel, will make the distance advanced by the screw through the water 4·7 feet per revolution, leaving the difference between this and the pitch, namely 1·13 feet, to be accounted for on the supposition that the screw blades had broken laterally through the water to that extent. It would be proper to apply some correction to this computation, which would represent the increased resistance due to the immersion of the screw in the water; for a column of water cannot be moved in the direction of its axis beneath the surface, without giving motion to the superincumbent water, and the inertia of this superincumbent water must, therefore, be taken into the account. In the experiment upon the Minx, the depth of this superincumbent column was but small. The total amount of the slip was 36·53 per cent.; and there will not be much error in setting down about one half of this as due to the recession of the water in the direction of the vessel's track, and the other half as due to the lateral penetration of the screw blades.

601. *Q.*—Is it not important to make the stern of screw vessels very fine, with the view of diminishing the slip, and increasing the speed?

A.—It is most important. The Rifleman, a vessel of 486 tons, had originally engines of 200 horses power, which propelled her at a speed of 8 knots an hour. The Teazer, a vessel of 296 tons, had originally engines of 100 horses power, which propelled her at a speed of 6½ knots an hour. The engines of the Teazer were subsequently transferred to the Rifleman, and new engines of 40 horse power were put into the Teazer. Both vessels were simultaneously sharpened at the stern, and the result was, that the 100 horse engines drove the Rifleman, when sharpened, as fast as she had previously been driven by the 200 horse engines; and the 40 horse engines drove the Teazer, when sharpened, a knot an hour faster than she had previously been driven by the 100 horse engines. The immersion of both vessels was kept unchanged in each case; and the 100 horse engines of the Teazer, when transferred to the Rifleman, drove that vessel, after she had been sharpened, 2 knots an hour faster than they had previously driven a vessel not much more than half the size. These are important facts for every one to be acquainted with who is interested in the success of screw vessels, and who seeks to obtain the maximum of efficiency with the minimum of expense.*

PROPORTIONS OF SCREWS.

602. *Q.*—In fixing upon the proportions of a screw proper to propel any given vessel, how would you proceed?

A.—I would first compute the probable resistance of the vessel, and I would be able to find the relative resistances of the screw and hull, and in every case it is advisable to make the screw as large in diameter as possible. The larger the screw is, the greater will be the efficiency of the engine in propelling the vessel; the larger will be the ratio of the pitch to the diameter, which produces a maximum effect; and the smaller will be the length of the screw or the fraction of a convolution to produce a maximum effect.

603. *Q.*—Will you illustrate this doctrine by a practical example?

A.—The French screw steamer Pelican was fitted successively with two screws of four blades, but the diameter of the first screw was 98·42 inches, and the diameter of the second 54 inches. If the efficiency of the first screw by represented by 1, that of the second screw will be represented by ·823, or, in other words, if the first screw would give a speed of 10 knots, the second would give little more than 8. The most advantageous

---

* See Treatise on the Screw Propeller, by John Bourne, C. E.

ratio of pitch to diameter was found to be 2·2 in the case of the large screw, and 1·384 in the case of the small. The fraction of a convolution which was found to be most advantageous was ·281 in the case of the large screw, and ·450 in the case of the small screw.

604. *Q.*—Were screws of four blades found to be more efficient than screws with two?

A.—They were found to have less slip, but not to be more efficient, the increased slip in those of two blades being balanced by the increased friction in those of four. Screws of two blades, to secure a maximum efficiency, must have a finer pitch than screws of four.

605. *Q.*—Are the proportions found to be most suitable in the case of the Pelican applicable to the screws of other vessels?

A.—Only to those which have the same relative resistance of screw and hull. Taking the relative resistance to be the area of immersed midship section, divided by the square of the screw's diameter, it will in the case of the Rattler be $\frac{380}{100}$ or 3·8. From the experiments made by MM. Bourgois and Moll on the screw steamer Pelican, they have deduced the proportions of screws proper for all other classes of vessels, whether the screws are of two, four, or six blades.

606. *Q.*—Will you specify the nature of their deductions?

A.—I will first enumerate those which bear upon screws with two blades. When the relative resistance is 5·5 the ratio of pitch to diameter should be 1·006, and the fraction of the pitch or proportion of one entire convolution should be 0·454. When the relative resistance is 5, the ratio of pitch to diameter should be 1·069, and fraction of pitch 0·428; relative resistance 4·5, pitch 1·135, fraction 0·402; relative resistance 4, pitch 1·205, fraction 0·378; relative resistance 3·5, pitch 1·279, fraction 0·355; relative resistance 3, pitch 1·357, fraction 0·334; relative resistance 2·5, pitch 1·450, fraction 0·313; relative resistance 2, pitch 1·560, fraction 0·294; relative resistance 1·5, pitch 1·682, fraction 0·275. The relative resistance of 4 is that which is usual in an auxiliary line of battle ship, 3·5 in an auxiliary frigate, 3 in a high speed line of battle ship, 2·5 in a high speed frigate, 2 in a high speed corvette, and 1·5 in a high speed despatch boat.

607. *Q.*—What are the corresponding proportions of screws of four blades?

A.—The ratios of the pitches to the diameter being for each of the relative resistances enumerated above, 1·342, 1·425, 1·513, 1·607, 1·705, 1·810, 1·933, 2·080, and 2·243, the respective fractions of pitch or fractions of a whole convolution will be 0·455, 0·428, 0·402, 0·378, 0·355, 0·334, 0·313, 0·294, and 0·275.

608. *Q.*—And what are the corresponding proportions proper for screws of six blades?

A.—Beginning with the relative resistance of 5·5 as before, the proper ratio of pitch to diameter for that and each of the successive resistances in the case of screws with six blades, will be 1·677, 1·771, 1·891, 1·2009, 2·131, 2·262, 2·416, 2·600, 2·804; and the respective fractions of pitch will be 0·794, 0·749, 0·703, 0·661, 0·621, 0·585, 0·548, 0·515, and 0·481. These are the proportions which will give a maximum performance in every case.*

SCREW VESSELS WITH FULL AND AUXILIARY POWER.

609. *Q.*—Do you consider that the screw propeller is best adapted for vessels of full power, or for vessels with auxiliary power?

A.—It is, in my opinion, best adapted for vessels with auxiliary power, and it is a worse propeller than paddle wheels for vessels which have habitually to encounter strong head winds. Screw vessels are but ill calculated—at least as constructed heretofore—to encounter head winds, and the legitimate sphere of the screw is in propelling vessels with auxiliary power.

610. *Q.*—Does the screw act well in conjunction with sails?

A.—I cannot say it acts better than paddles, except in so far

---

* In my Treatise on the Screw Propeller I have gone into these various questions more fully than would consort with the limits of this publication.

as it is less in the way and is less affected by the listing or heeling over of the ship. A small steam power, however, acts very advantageously in aid of sails, for not only does the operation of the sails in reducing the resistance of the hull virtually increase the screw's diameter, but the screw, by reducing the resistance which has to be overcome by the sails and by increasing the speed of the vessel, enables the sails to act with greater efficiency, as the wind will not rebound from them with as great a velocity as it would otherwise do, and a larger proportion of the power of the wind will also be used up. In the case of beam winds, moreover, the action of the screw, by the larger advance it gives to the vessel will enable the sails to intercept a larger column of wind in a given time. It appears, therefore, that the sails add to the efficiency of the screw, and that the screw also adds to the efficiency of the sails.

611. *Q.*—What is the comparative cost of transporting merchandise in paddle steamers of full power, in screw steamers of auxiliary power, and in sailing ships?

A.—That will depend very much upon the locality where the comparison is made. In the case of vessels performing distant ocean voyages, in which they may reckon upon the aid of uniform and constant winds, such as the trade winds or the monsoon, sailing ships of large size will be able to carry more cheaply than any other species of vessel. But where the winds are irregular and there is not much sea room, or for such circumstances as exist in the Channel or Mediterranean trades, screw vessels with auxiliary power will constitute the cheapest instrument of conveyance.

612. *Q.*—Are there any facts recorded illustrative of the accuracy of this conclusion?

A.—A full paddle vessel of 1000 tons burden and 350 horses power, will carry about 400 tons of cargo, besides coal for a voyage of 500 miles, and the expense of such a voyage, including wear and tear, depreciation, &c., will be about 190*l.* The duration of the voyage will be about 45½ hours. A screw vessel of 400 tons burden and 100 horses power, will carry the same amount of cargo, besides her coals, on the same voyage, and the expense of the voyage, including wear and tear, depreciation, &c., will be not much more than 60*l.* An auxiliary screw vessel, therefore, can carry merchandise at one third of the cost of a full-powered paddle vessel. By similar comparisons made between the expense of conveying merchandise in auxiliary screw steamers and sailing ships on coasting voyages, it appears that the cost in screw steamers is about one third less than in the sailing ships; the greater expedition of the screw steamers much more than compensating for the expense which the maintenance of the machinery involves.

SCREW AND PADDLES COMBINED.

613. *Q.*—Would not a screw combined with paddles act in a similarly advantageous way as a screw or paddles when aided by the wind?

A.—If in any given paddle vessel a supplementary screw be added to increase her power and speed, the screw will act in a more beneficial manner than if it had the whole vessel to propel itself, and for a like reason the paddles will act in a more beneficial manner. There will be less slip both upon the paddles and upon the screw than if either had been employed alone; but the same object would be attained by giving the vessel larger paddles or a larger screw.

614. *Q.*—Have any vessels been constructed with combined screw and paddles?

A.—Not any that I know of, except the great vessel built under the direction of Mr. Brunel. The Bee many years since was fitted with both screw and paddles, but this was for the purpose of ascertaining the relative efficiency of the two modes of propulsion, and not for the purpose of using both together.

615. *Q.*—What would be the best means of accelerating the speed of a paddle vessel by the introduction of a supplementary screw?

A.—If the vessel requires new boilers, the best course of procedure would be to work a single engine giving motion to the screw with high pressure steam, and to let the waste steam from the high pressure engine work the paddle engines. In this way the power might be doubled without any increased expenditure of fuel per hour, and there would be a diminished expenditure per voyage in the proportion of the increased speed.

616. *Q.*—What would the increased speed be by doubling the power?

A.—The increase would be in the proportion of the cube root of 1 to the cube root of 2, or it would be 1·25 times greater. If, therefore, the existing speed were 10 miles, it would be increased to 12½ miles by doubling the power, and the vessel would ply with about a fourth less coals by increasing the power in the manner suggested.

617. *Q.*—Is not high pressure steam dangerous in steam vessels?

A.—Not necessarily so, and it has now been introduced into a good number of steam vessels with satisfactory results. In the case of locomotive engines, where it is used so widely, very few accidents have occurred; and in steam vessels the only additional source of danger is the salting of the boiler. This may be prevented either by the use of fresh water in the boiler, or by practising a larger amount of blowing off, to insure which it should be impossible to diminish the amount of water sent into the boiler by the feed pump, and the excess should be discharged overboard through a valve near the water level of the boiler, which valve is governed by a float that will rise or fall with the fluctuating level of the water. If the float be a copper ball, a little water should be introduced into it before it is soldered or brazed up, which will insure an equality of pressure within and without the ball, and a leakage of water into it will then be less likely to take place. A stone float, however, is cheaper, and if properly balanced will be equally effective. All steam vessels should have a large excess of boiling feed water constantly flowing into the boiler, and a large quantity of water constantly blowing off through the surface valves, which being governed by floats will open and let the superfluous water escape whenever the water level rises too high. In this way the boiler will be kept from salting, and priming will be much less likely to occur. The great problem of steam navigation is the economy of fuel, since the quantity of fuel consumed by a vessel will very much determine whether she is profitable or otherwise. Notwithstanding the momentous nature of this condition, however, the consumption of fuel in steam vessels is a point to which very little attention has been paid, and no efficient means have yet been adopted in steam vessels to insure that measure of economy which is known to be attainable, and which has been attained already in other departments of engineering in which the benefits of such economy are of less weighty import. It needs nothing more than the establishment of an efficient system of registration in steam vessels, to insure a large and rapid economy in the consumption of fuel, as this quality would then become the test of an engineer's proficiency, and would determine the measure of his fame. In the case of the Cornish engines, a saving of more than half the fuel was speedily effected by the introduction of the simple expedient of registration. In agricultural engines a like economy has speedily followed from a like arrangement; yet in both of these cases the benefits of a large saving are less eminent than they would be in the case of steam navigation; and it is to be hoped that this expedient of improvement will now be speedily adopted.