www.e-rara.ch

A course of lectures on natural philosophy and the mechanical arts

Young, Thomas

London, 1807

ETH-Bibliothek Zürich

Persistent Link: https://doi.org/10.3931/e-rara-14360

Lecture XXVII. On the regulation of hydraulic forces.

www.e-rara.ch
Die Plattform e-rara.ch macht die in Schweizer Bibliotheken vorhandenen Drucke online verfügbar. Das Spektrum reicht von Büchern über Karten bis zu illustrierten Materialien – von den Anfängen des Buchdrucks bis ins 20. Jahrhundert.

e-rara.ch provides online access to rare books available in Swiss libraries. The holdings extend from books and maps to illustrated material – from the beginnings of printing to the 20th century.

e-rara.ch met en ligne des reproductions numériques d’imprimés conservés dans les bibliothèques de Suisse. L’éventail va des livres aux documents iconographiques en passant par les cartes – des débuts de l’imprimerie jusqu’au 20e siècle.

e-rara.ch mette a disposizione in rete le edizioni antiche conservate nelle biblioteche svizzere. La collezione comprende libri, carte geografiche e materiale illustrato che risalgono agli inizi della tipografia fino ad arrivare al XX secolo.

Nutzungsbedingungen Dieses Digitalisat kann kostenfrei heruntergeladen werden. Die Lizenzierungsart und die Nutzungsbedingungen sind individuell zu jedem Dokument in den Titelinformationen angegeben. Für weitere Informationen siehe auch [Link]

Terms of Use This digital copy can be downloaded free of charge. The type of licensing and the terms of use are indicated in the title information for each document individually. For further information please refer to the terms of use on [Link]

Conditions d'utilisation Ce document numérique peut être téléchargé gratuitement. Son statut juridique et ses conditions d'utilisation sont précisés dans sa notice détaillée. Pour de plus amples informations, voir [Link]

Condizioni di utilizzo Questo documento può essere scaricato gratuitamente. Il tipo di licenza e le condizioni di utilizzo sono indicate nella notizia bibliografica del singolo documento. Per ulteriori informazioni vedi anche [Link]

LECTURE XXVII.

ON THE REGULATION OF HYDRAULIC FORCES.

THOSE modifications of the motions of fluids which are employed either for conducting them from place to place, or for applying their powers to the production of mechanical effects, may be considered as constituting a separate division of practical hydraulics, which is analogous to the subject of general machinery in practical mechanics.

A supply of water may be obtained from a reservoir, situated above the level at which it is wanted, whatever its distance may be, either by means of open canals, or aqueducts, or of closed pipes. Where an uninterrupted declivity cannot be obtained, it is necessary to employ pipes, which may be bent upwards or downwards at pleasure, provided that no part of them be more than thirty feet above the reservoir, and when the pipe is once filled, the water will continue to flow from the lower orifice; but it is best in all such cases to avoid unnecessary angles; for when the pipe rises and falls again, a portion of the air, which is always contained in water, is frequently collected in the angle, and very materially impedes the progress of the water through the pipe. When the bent part is wholly below the orifices of the pipe, this air may be discharged by various methods. The ancients used small upright pipes, called columnaria, rising from the convexity of the principal pipe, to the level of the reservoir, and suffering the air to escape without wasting any of the water. It may however frequently be inconvenient or impossible to apply a pipe of this kind; and the same purpose may be answered, by fixing on the pipe a box containing a small valve, which opens downwards, and is supported by a float, so as to remain shut while the box is full of water, and to fall open when any air is collected in it. (Plate XXI. Fig. 288.)

If the pipe were formed into a siphon, having its flexure above both orifices, it would be necessary to bend it upwards at the extremities, in order to keep it always full: but in this case the accumulation of the air would be extremely inconvenient, since it would collect so much the more copiously, as the water in the upper part of the pipe would be more free from pressure, and neither of the methods which have been mentioned would be of any use in extricating it. It has been usual in such cases to force a quantity of water violently through the pipe, in order to carry the air with it; but perhaps the same effect might be produced much more easily, by making a small airtight valve in the upper part of the pipe, opening outwards, and a stopcock immediately before it: the stopcock being suddenly turned as often as might be necessary, the momentum of the water in the pipe would probably carry it forwards with sufficient force to throw out the air; or, if it were necessary external pressure might be added, and the air might even in this manner be discharged by the valve much more readily than without it. But it might be still simpler to have a pretty large vessel of water screwed on to the pipe, which would not be filled with air for a considerable time; and which, when full, might be taken off and replenished with water. (Plate XXI. Fig. 285.)

The diameter of a pipe, required for conveying a given quantity of water to a given distance, may be calculated from the experiments of Mr. Buat, which have been already mentioned. Pipes are usually made of wood, of lead, or of cast iron; but most commonly of lead; and of late tinned copper has been employed with considerable advantage. A pipe of lead will bear the pressure of a column of water 100 feet high, if its thickness be one hundredth of its diameter, or even less than this; but when any alternation of motion is produced, a much stronger pipe is required, and it is usual to make leaden pipes of all kinds far thicker than in this proportion.

The form and construction of stopcocks and valves are very various, according to their various situations and uses. Stopcocks usually consist of a cylindrical or conical part, perforated in a particular direction, and capable of being turned in a socket formed in the pipe, so as to open or shut the passage of the fluid, and sometimes to form a communication with either of two or more vessels at pleasure. A valve is employed where the fluid is to be allowed to pass in one direction only, and not to return. For water, those valves are the best which interrupt the passage least; and none appears to fulfil this condition better than the common clack valve of leather, which is generally either single, or divided into two parts; but it is sometimes composed of four parts, united so as to form a pyramid, nearly resembling the double and triple valves which are formed by nature in the hearts of animals. A board, or a round flat piece of metal, divided unequally by an axis on which it moves, makes also a very good simple valve. Where a valve is intended to intercept the passage of steam, it must be of metal; such a valve is generally a flat plate, with its edge ground a little conically, and guided in its motion by a wire or pin. For air, valves are commonly made of oiled silk, supported by a perforated plate or grating. (Plate XXI. Fig. 286, 287.)

Before we consider the application of the force of fluids in motion to practical purposes, we must attend to the methods of measuring the velocity of their motions. This may be done either by a comparison with linear measures, or by instruments founded on the laws of hydraulic pressure. One of the best of such instruments is the tube invented by Pitot, and improved by Buat. A funnel is presented to the stream, and the water in a vertical tube connected with it is elevated above the level of the river, nearly to the height corresponding to the velocity: but it is said that the result will be less liable to error, if the funnel be covered by a plate with a small orifice in its centre, the elevation being in this case always half as great again as the height due to the velocity. Other instruments, intended for the same purpose, require some previous experiments for determining the degree in which they are affected by different velocities; in this manner the hydrometrical fly is adjusted; the impulse of the water on two inclined planes turning an axis to which they are fixed, and by its means a series of wheels, with an index, which expresses the space described during the time of observation. Instruments similar to these have also sometimes been employed, for measuring the relative velocity, with which a ship under way passes through the water; and an apparatus, resembling Pitot's, has been adapted to this purpose by Captain Hamilton, with the addition of a tube inserted into it on a level with the surface of the water, which continually discharges a small stream into a reservoir with a velocity regulated by the pressure, and consequently equal or proportional to that of the ship itself. In this manner he obtains an accurate register of the whole distance described, including the effect of all the variations of the velocity. If the orifice be small, it will be necessary to attend to the temperature of the water, since the discharge is considerably retarded by any considerable degree of cold. But when the aperture, which determines the magnitude of the discharge, is wholly under water, as Captain Hamilton has placed it, this source of error is probably much diminished. (Plate XXII. Fig. 288, 289.)

The motions of the air may also be measured by instruments similar to those which are employed for determining the velocity of streams of water. The direction of the wind is sometimes indicated by a wind dial, consisting simply of an index, connected by wheels with a common vane or weathercock. Its velocity may be found by means of wind gages of different kinds: these are sometimes constructed by opposing a flat surface to the wind, the pressure being measured by the flexure of a spring, or by the winding up of a weight on a spiral barrel; and sometimes by receiving the stream in the mouth of a funnel, so as to raise a column of water, in a vertical tube, to a height equivalent to the pressure, or to condense a quantity of air inclosed in a cavity, to a degree which is indicated by the place of a small portion of mercury, moving in a horizontal tube, which leads to the cavity. A little windmill, like the hydrometrical fly, may also be employed for measuring the velocity of the wind, with the assistance of a watch.

The principal methods of applying the force of fluids to useful purposes are to employ their weight, their impulse, or their pressure. The weight of water may be applied, by collecting it in a reservoir, which alternately ascends and descends, by causing it to act within a pipe on a moveable piston, or by conducting it into the buckets of a revolving wheel; its impulse may be directed either perpendicularly or obliquely against a moveable surface; and its pressure may be obtained, without any immediate impulse, by causing a stream to flow horizontally out of a moveable pipe which revolves round an axis. The force of the air can only be applied by means of its impulse, and this may be employed either perpendicularly or obliquely.

When water is collected in a single reservoir, which serves to work a pump or to raise a weight, the mode of its operation may be determined from mechanical considerations only; and it is obvious that if we are desirous of preserving the whole force of the water, we must employ a second reservoir to be filled during the descent of the first, which may either descend in its turn, or empty itself into the first when it has ascended again to its original situation. The action of a column of water, inclosed in a pipe, is of a nature nearly similar to that of such a reservoir, excepting that the apparatus is more liable to friction; the arrangement of its parts is nearly similar, although in an inverted position, to that which is more commonly employed for raising water by means of pumps. But both these methods of employing the weight of water, are in great measure confined to those cases in which it is to be procured in a small quantity, and may be allowed to descend through a considerable height, and when the circumstances do not allow us to employ machines which require a greater space.

We have seen that in order to determine the effect of any force employed in machinery, we must consider not only its magnitude, but also the velocity with which it can be brought into action, and we must estimate the ultimate value of the power, by the joint ratio, or the product, of the force and the velocity. Thus, if we had a corn mill, for example, in which we wished the millstone to revolve with a certain velocity, and to overcome a given resistance, and supposing that this effect could be obtained by means of a certain train of wheels from a given source of motion; if the velocity of the motion at its source be reduced to one half, we must double the diameter of one of the wheels by which the force is communicated, in order to give the millstone the desired velocity, and thus we must introduce a mechanical disadvantage, which can only be compensated by a double intensity in the force at its origin.

If we apply this estimation of effect to the motion of an overshot wheel, we shall find that the velocity of the wheel, and consequently its breadth, and the magnitude of its buckets, is perfectly indifferent with respect to the value of its operation: for supposing the stream to enter the buckets with the uniform velocity of the wheel, the quantity of water in the wheel at any one time, and consequently the pressure, must be inversely as the velocity, so that the product of the force into the velocity will be the same, however they may separately vary. If, however, the velocity were to become very considerable, it would be necessary to sacrifice a material part of the fall, in order that the water might acquire this velocity before its arrival at the wheel; but a fall of one foot, or even less, is sufficient for producing any velocity that would be practically convenient: and it is obvious, on the other hand, that a certain velocity may be procured from a wheel moving rapidly, with less machinery than from another which moves more slowly. In general the velocity of the surface of the wheel is between two and six feet in a second; and whether it be greater or smaller, the force actually applied will always be equal in effect to the weight of a portion of the stream employed, equal in length to the height of the wheel. In order to avoid the resistance which might be occasioned by the stagnant water below the wheel, it is a good practice to turn the stream backwards upon its nearer half, so that the water, when discharged, may run off in the general direction of its motion. (Plate XXII. Fig. 290.)

If we suffer the stream of water to acquire the utmost velocity that the whole fall can produce, and to strike horizontally against the floatboards of an undershot wheel, or if we wish to employ the force of a river running in a direction nearly horizontal, the wheel must move, in order to produce the greatest effect, with half the velocity of the stream. For the whole quantity of water impelling the floatboards is nearly the same, whatever may be the velocity, especially if the wheel is properly inclosed in a narrow channel, and hence it is easy to calculate that the greatest possible effect will be produced when the relative velocity of the stream, striking the floatboards, is equal to the velocity of the wheel itself. The pressure on the floatboards is equal to that of a stream containing the same quantity of water, and striking a fixed obstacle with half the velocity, that is, such a stream as escapes from the wheel, which must be twice as deep or twice as wide as the original stream, since its motion is only one half as rapid; and a column of such a stream, of twice the height due to its velocity, that is, of half the height of the fall, being, as we have already seen, the measure of the hydraulic pressure, this force will be precisely half as great as that of a similar column, acting on an overshot wheel, which moves with the same velocity. But the stream thus retarded will not retain the other half of its mechanical power; since its greatest effect will be in the same proportion to that of an equal stream acting on an overshot wheel with one fourth of the fall of the former: and the remaining fourth of the power is lost in producing the change of form of the water and in overcoming its friction. In whatever way we apply the force of water, we shall find that the mechanical power which it possesses must be measured by the product of the quantity multiplied by the height from which it descends: for example, a hogshead of water capable of descending from a height of 10 feet, possesses the same power as 10 hogsheads descending from a height of one foot; and a cistern filled to the height of 10 feet above its orifice possesses 100 times as much power as the same cistern filled to the height of one foot only.

When, therefore, the fall is sufficiently great, an overshot wheel is far preferable to an undershot wheel, and where the fall is too small for an overshot wheel, it is most advisable to employ a breast wheel, which partakes of its properties; its floatboards consisting of two portions meeting at an angle, so as to approach to the nature of buckets, and the water being also in some measure confined within them by the assistance of a sweep or arched channel which follows the curve of the wheel, without coming too nearly into contact with it, so as to produce unnecessary friction. When the circumstances do not admit even of a breast wheel, we must be contented with an undershot wheel: it is recommended, for such a wheel, that the floatboards be so placed as to be perpendicular to the surface of the water at the time that they rise out of it: that only one half of each should ever be below the surface, and that from three to five should be immersed at once, according to the magnitude of the wheel. Sometimes, however, it has been thought eligible to employ a much smaller number: thus the water wheel which propels Mr. Symington's steam boat has only six floatboards in its whole circumference. (Plate XXII. Fig. 291, 292.)

Since the water escaping from an undershot wheel still retains a part of its velocity, it is obvious that this may be employed for turning a second wheel, if it be desirable to preserve as much as possible of the force. In this case, by causing the first wheel to move with two thirds of the velocity of the stream, the whole effect of both will be one third greater than that of a single wheel placed in the same stream; but it must be considered that the expense of the machinery will also be materially increased.

Considerable errors have frequently been made by mathematicians and practical mechanics in the estimation of the force of the wind or the water on oblique surfaces: they have generally arisen from inattention to the distinction between pressure and mechanical power. It may be demonstrated that the greatest possible pressure of the wind or water, on a given oblique surface at rest, tending to turn it in a direction perpendicular to that of the wind, is obtained when the surface forms an angle of about 55° with the wind; but that the mechanical power of such a pressure, which is to be estimated from a combination of its intensity with the velocity of the surface, may be increased without limit by increasing the angle of inclination, and consequently the velocity. The utmost effect that could be thus obtained would be equal to that of the same wind or stream acting on the floatboards of an undershot wheel: but since in all practical cases the velocity is limited, the effect will be somewhat smaller than this: for example, if the mean velocity of the sails or floatboards be supposed equal to that of the wind, the mechanical power will be more than four fifths as great as that of an undershot wheel, that is, in the case of a windmill, more than four fifths of the utmost effect that can be obtained from the wind. In such a case Maclaurin has shown that the sails ought to make an angle of 74° with the direction of the wind: but in practice it is found most advantageous to make the angle somewhat greater than this, the velocity of the extremities of the sails being usually, according to Mr. Smeaton, more than twice as great as that of the wind. It appears, therefore, that the oblique sails of the common windmill are in their nature almost as well calculated to make the best use of any hydraulic force as an undershot wheel; and since they act without intermission throughout their whole revolution, they have a decided advantage over such machines as require the sails or fans to be exposed to a more limited stream of the wind, during one half only of their motion, which is necessary in the horizontal windmill, where a screen is employed for covering them while they are moving in a direction contrary to that of the wind: and such machines, according to Smeaton, are found to perform little more than one tenth of the work of those which are more usually employed. The sails of a common windmill are frequently made to change their situation according to the direction of the wind, by means of a small wheel, with sails of the same kind, which turns round whenever the wind strikes on either side of it, and drives a pinion turning the whole machinery; the sails are sometimes made to furl or unfurl themselves, according to the velocity of the wind, by means of a revolving pendulum, which rises to a greater or less height, in order to prevent the injury which the flour would suffer from too great a rapidity in the motion, or any other accidents which might happen in a mill of a different nature. The inclination of the axis of a windmill to the horizon is principally intended to allow room for the action of the wind at the lower part, where it would be weakened if the sails came too nearly in contact with the building, as they must do if they were perfectly upright. When it is necessary to stop the motion of a windmill, a break is applied to the surface of a large wheel, so that its friction operates with a considerable mechanical advantage. Water wheels with oblique floatboards are sometimes used with good effect in China and in the south of France: for tide wheels, such floatboards have the advantage that they may be easily made to turn on a hinge with the stream, so as to impel the wheel in the same direction whether the tide be flowing or ebbing. (Plate XXII. Fig. 293.)

A smoke jack is a windmill in miniature; a kite affords a very familiar example of the effect of the oblique impulse of the air, of which the action first causes a pressure perpendicular to the surface of the kite, and this force, combined with the resistance of the string, produces a vertical result capable of counteracting the weight of the kite. (Plate XXII. Fig. 294.)

The counterpressure of the water, occasioned by the escape of a stream from a moveable reservoir, was applied by Parent to the purpose of turning a millstone, and various other authors have described machines of a similar nature: they may be constructed with little or no wheel work, and it does not appear to be necessary that much of the force of the water should be lost in their operation; but they have never been practically employed with success, nor have they perhaps ever had a fair trial.

The art of seamanship depends almost entirely on the management of the forces and resistances of air and water, and if the laws of hydraulic pressure, with respect to oblique and curved surfaces, were more completely ascertained, we might calculate not only what the motions of a ship would be under any imaginable circumstances, but we might also determine precisely what would be the best possible form of a ship, and what the best arrangement of her rigging.

When a ship is sailing immediately before the wind, little or no art is required in setting her sails, and her velocity is only limited by that of the wind, and by the resistance of the water: but for sailing with a side wind, it becomes necessary that the immediate force of the wind should be considerably modified.

If we had a circular vessel or tub, with a single mast, and a sail perfectly flat, and if the sail were placed in a direction deviating but little from that of the wind, the tub would begin to move in a direction nearly at right angles to that of the wind, since the impulse of the wind acts almost entirely in a direction perpendicular to that of the sail: but the slightest inequality of the dimensions of the sail, or of the force of the wind, would immediately disturb the position of the vessel; and in order to avoid this inconvenience, it would be necessary to have a moveable body projecting into the water, so as to create a resistance by means of which the vessel might be steered, and the sail confined to its proper place: and this might be done more effectually by changing the form of the vessel from round to oval; it would then also have the advantage of moving much more easily through the water in the direction of its length than a circular vessel of equal size, and of creating still more resistance in a transverse direction, so that when urged by an oblique force, it would move in some measure obliquely, but always much more nearly in the direction of its length than of its breadth. The angular deviation from the track of the ship is called its lee way, and if we know the direction of the sails, and the actual proportions of the resistances opposed to the ship's motion in different directions, we may calculate from these resistances the magnitude of the angular deviation or lee way: but hitherto such calculations have generally indicated a lee way three or four times as great as that which has been observed. The use of the keel is not only to assist in confining the motion of the ship to its proper direction, but also to diminish the disposition to vibrate from side to side, which would interfere with the effect of the sails, and produce many other inconveniences. When the principal force of the wind is applied to the anterior part of the ship, her head would be naturally turned from the wind if the rudder were not made to project from the stern in a contrary direction, and to present the surface of an inclined plane to the water which glides along the keel, so as to preserve the ship, by means of the pressure which it receives, in any direction that may be required for her manoeuvres. Commonly, however, although the sails may be so arranged that the principal force of the wind appears to be on the fore part of the ship, the curvature of the sails, or some other cause, throws the pressure further backwards, and the action of the rudder is necessary to prevent the ship's head turning towards the wind. (Plate XXII. Fig 295.)

When a ship is steering in this manner on a side wind, the effect of the wind has a natural tendency to overset her, and if she is too crank, that is, deficient in stability, she cannot sail well, otherwise than directly before the wind. The place of the centre of gravity, compared with that of the metacentre, or imaginary centre of pressure, determines the degree of stability, and the most general way of increasing it is to lessen the weight of the upper part, and of the rigging of the vessel, to diminish her height, or to increase her breadth, and to stow the ballast as low as possible in the hold. Too little attention has frequently been paid to this subject, as well as to many other departments of naval architecture; and although mere theoretical investigations have hitherto been but of little service to the actual practice of seamanship, yet it cannot be doubted that an attention to what has already been discovered of the laws of hydrodynamics, as well as to the principles of mechanics in general, must be of great advantage to the navigator, in enabling him to derive from his own experience all the benefits, which a correct mode of reasoning is capable of procuring him.