AN

ESSAY

ON THE

MECHANICAL PRINCIPLES

OF THE

PLOUGH.

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ADVERTISEMENT.

THE design of this performance is to assist any person acquainted with the simplest principles of mechanics to understand the construction, manner of operation, and best form of the plough; so that, by attending to the nature and state of the soil he has to manage, he may know what construction of this instrument is best suited for accomplishing the purposes he has in view; and be enabled to give directions for making it accordingly. If the Author is successful in this attempt, there can be no question that he will render an important service to his country.

AN ESSAY ON THE PLOUGH.

THE plough affords, in every civilized country, employment for almoſt one half its inhabitants; and is the chief means of procuring ſubſiſtence for the whole. But, notwithſtanding this great and general utility, and that agriculture has commonly accompanied ſcience and philoſophy, the plough is an inſtrument whereon theory has never condeſcended to beſtow the ſlighteſt attention. Whether this neglect has ariſen from the apprehended meanneſs or difficulty of the ſubject, or perhaps from both, I ſhall not undertake to decide; but rather proceed to the more agreeable and uſeful taſk, the attempting to ſupply the defect, by an an inveſtigation of the mechanical principles on which it is conſtructed, with a view to determine its beſt and moſt advantageous form.

The moſt correct general idea we can conceive of the plough, or the inſtrument in mechanics whoſe form and manner of operation it moſt nearly reſembles, is that of a half-wedge*, abſtracting from the beam and handles, which are ſubſervient intirely to the purpoſes of moving and managing it. This view, indeed, is ſo varied and diſguiſed by a number of circumſtances, that the reſemblance may not perhaps immediately appear. It will be proper, however, to keep it in our eye, as the beſt ground-work to which every part of the deſcription may be referred: And, when all deviations are explained and accounted for, the ſimilarity will probably be found greater than is expected.

The

* ABC, fig. I. is a whole wedge. Divide the angle at B into two equal parts, by the line BD, which line will biſect the wedge, and point out its direction; and conſequently DBC or ABC, fig. II. will be a half wedge. AB, fig. II. is the flat or left ſide; BC is the right or projected ſide; AC is the back; and the narrow ſide ABC is the edge.

The plough, then, conſidered as a half-wedge, moves on one of its * edges, with its flat ſide towards the firm ground, and its inclined ſide towards the ploughed ground. The face of the coulter, which repreſents the ſharp angle of the wedge, cuts off the furrow from the unploughed land. The left ſide of the plough being flat, and applied to the firm ground, which cannot give way, makes the plough proceed in a ſtraight line, and take off a furrow of equal breadth; and the right ſide being inclined outwards, gradually removes the earth to a convenient diſtance, turns, and breaks it.

The left ſide of the plough reſembles very nearly the flat ſide of the half-wedge, becauſe it is almoſt wholly in the † ſame plane, and has no inclination to the line of direction in which the plough moves, or the

force

* The line AD, fig. II. repreſents the left ſide of the furrow; AB the flat or left ſide of the plough applied to the firm ground; BC its inclined, or right ſide, applied to the ploughed land.

† Different things are ſaid to be in the ſame plane, when they are ſituated in the ſame plane ſurface, whether that ſurface be real or imaginary.

force that pulls it acts. The necessity of its having no inclination is obvious; for, had the direction of the plough not coincided with the direction of the force, but pointed either to the right or left, the constant tendency of the inclination must have been, to turn the plough from the right direction, either toward the furrow or the firm ground. And this is the reason why the plough is a half-wedge *. By its being a half-wedge, the direction of it coincides exactly with the direction of the force; whereas, had it been greater than a half-wedge, its direction must have pointed to the

* AD, fig. II. is the direction of the plough, or of the force that moves it. AB is the direction of the plough, or half-wedge, according to note first; and these two in this case coincide. Were the plough greater than a half-wedge, as ABC, fig. III. then, supposing ABE the direction of the force, or the line of the furrow, DBF will be the natural direction of the plough tending to the left of the line of the force. Were the plough less than a half-wedge, as DBC, fig. IV. DBF being the line of force, ABE will be the natural direction of the plough to the right of the line of force.

the left of that of the force; and, consequently, its tendency been towards the firm ground. Had it been less, its direction must have pointed to the opposite side, and its tendency on that account been towards the ploughed land.

The right side of the plough deviates considerably from the form of the inclined side of the half-wedge. It is not, like the latter, perpendicular, but inclined a little to the horizon; by which means the plough now takes the figure of a half-wedge, whose upper edge is narrower than its lower. The design of this part of its construction is to raise and turn the earth; for, as the plough is wider below than above, it first insinuates its lowest and most inclined part below the nearest side of the earth of the furrow, raises that side gently up, and, penetrating still farther as it proceeds, gradually turns the earth over. Had the right side of the plough been perpendicular to the horizon, or exactly in this respect resembled the wedge, it could not have raised or turned the earth of the furrow, but must have cut the earth out, and pushed it aside, with the ſame ſurface uppermoſt, as a common wedge ſeparates the parts of any body between which it is made to paſs.

The earth now being raiſed up, the next ſtep is to place it on its edge, or lay it on its back, as ſhall be judged moſt proper.

For this purpoſe, the mould-board is generally made ſteeper, or leſs ſloping toward the hinder than the fore-part. But what chiefly produces the effect now ſpecified is, the raiſing of the hinder part of it above the level of the fore-part. By this conſtruction the mould-board riſes and projects at the ſame time *. The preſſure on the different parts of the earth of the furrow takes place in a correſpondent manner; the loweſt parts are leaſt preſſed, the higher ones ſtill more, according to their height. It is abundantly plain, that, by this form, the plough muſt place the earth on its edge, or turn it more or leſs over, according as the projection and inclination of this part are greater or leſs; and alſo that the reſemblance to the wedge,

* AB, fig. 5. repreſents the ſurface of the ground or plane, on which the plough moves; BK, the riſe and projection of the mould-board above that plane.

wedge, in this view, would be expreſſed by cutting away the right hand angle of the edge on which it moves.

Any perſon in the leaſt acquainted with the inſtrument under conſideration, will eaſily perceive, that the deſcription now given of the right ſide of it, refers to the plough with the plain mould-board. The curved mould-board * is a little different in form, acts in a different manner, and is intended for a different kind of ſoil. It does not, however, oblige us to relinquiſh the compariſon with the wedge, which will be found here equally convenient and ſerviceable as before.

The curved mould-board is in general more perpendicular to the horizon than the plain one. But the fore-part, inſtead of being plain, is bent into a curved figure, reſembling a little the bow of a ſhip, ſo that here the upper and lower parts of the plough are nearly of the ſame breadth. Towards the other end, this board projects a good deal more above than below; and here the plough is wider above than below. It is eaſy

* See figure 6.

eaſy to perceive, how theſe changes in figure produce their correſpondent effects. For, as this board is, or ought to be, uſed in land ſo looſe that it does not riſe whole, the curve at the fore-end turns over ſuddenly the earth of the furrow, and, in ſo doing, ſeparates and bruiſes it; and the projection on the other end lays it ſloping backwards, to prevent its falling again into its former place. The hinder part of this board has no elevation; for, if it had, as the earth it moves through has not much coheſion, and does not riſe whole, a great part of it would not be ſtirred at all; which it is plain would happen to all the earth that ſhould lie below the elevation.

It is alſo eaſy to perceive, from the deſcription, how a few not very conſiderable changes in the inclined ſide of the half-wedge, would repreſent the figure of this mould-board *.

Another

* Suppoſe BC, fig. 7. a thick plain block, out of which a curved mould-board is to be formed; it muſt riſe by a ſmall projection above the plane from C to D, and by a ſtill greater projection from D to B, on the upper ſide, but not on the lower.

Another circumſtance, wherein the plough departs from the figure of the half-wedge is, the ſituation and inclination of the coulter †.

With regard to ſituation, the coulter is not placed where the inclination of the mould-board begins, which would render the reſemblance more compleat, but at a conſiderable diſtance before it; ſo that the plough acts, for ſome time, as a cutting inſtrument, before it begins to act as a wedge.

Or, the plough may be conſidered as a wedge whoſe inclination is different at different places, very ſmall for a certain length, but very conſiderable afterwards.

This ſituation of the coulter is a very ſimple but ingenious contrivance; for it both diminiſhes the reſiſtance, and makes the plough move with more ſteadineſs. It diminiſhes conſiderably the reſiſtance; becauſe the earth of the furrow is ſeparated and broken in ſome meaſure, before the mould-board reaches it, and in this looſe ſtate more readily gives way to the projection of the board.

Had

† Figure 5. and 6.

Had the coulter been placed where the inclination of the mould-board begins, the earth muſt have fallen upon the riſing ſide of the board almoſt entire, and reſiſted proportionally more according to its greater firmneſs.

This ſituation alſo greatly promotes the ſteady motion of the plough, by lengthening conſiderably the part that moves below the ſurface; for the longer or ſhorter this part is, the more or leſs ſteady muſt the motion be. Now, by the ſituation of the coulter, the plough gains the ſame advantages in point of length as if it were one continued wedge; and conſequently muſt be much leſs apt to be puſhed out of its direction, than it would be, if made ſhorter, by having the coulter placed nearer, or joining to the mould-board.

This ſituation promotes ſteady motion from another cauſe. The ſoil towards the furrow is always a little leſs firm, than that at ſome diſtance from it, being looſened by the treading of the cattle and rubbing of the plough. On this account, there is a conſtant tendency in the plough to leave the firmer ground,

ground, and deviate towards the ploughed land, where the reſiſtance is leſs, becauſe the ſoil is looſer. To counterbalance this tendency, the coulter is ſet inclining a little to the left*; ſo that at the point it riſes ſomewhat above the plane of the left ſide, and is one exception to what was formerly obſerved, that this ſide is all in one plane; and thus the coulter, both by moving in firmer ground, and by being inclined to the plane of the left ſide of the plough, communicates a more ſteady and uniform motion to the whole. Now, the ſame inclination would not have produced the ſame effects, if the ſituation of the coulter had been at or near the mould-board; becauſe the obſtructions, in that caſe, acting on a ſhorter lever, would produce correſpondently greater conſequences, and for this reaſon diſturb more the motion of the whole machine.

The other particular formerly mentioned, was

* Suppoſe the line AF, fig. 7. to repreſent the plane of the left ſide of the plough, F the point of the ſhare or ſock; then the point E may expreſs the lower end of the coulter placed to the left of the plane.

was the forward inclination of the coulter. The advantages of this poſition above a perpendicular one are very conſiderable. It balances the upward direction of force, which, without this, in ſome meaſure contrary direction of the coulter, would ſoon bring the plough out of the ground altogether*. It diminiſhes the reſiſtance in cutting the ſoil by converting it into oblique inſtead of being direct, which it would be by the perpendicular poſition. It laſtly facilitates greatly the cutting or tearing up of roots, by making them ſlide upon its edge, by which means, they are not only more readily but more eaſily cut or torn aſunder, as the plough acts againſt them with a ſhorter lever the higher they riſe.

The laſt circumſtance to be taken notice of is the form and uſe of the ſhare, commonly called in Scotland the ſock. In general, it is almoſt an exact repreſentation of the

* GB, fig. 8. is the inclination of the coulter, CED is the direction of the force, if there is only one force applied, and the mean direction, if there be two forces applied that act in different directions, as ſhall be afterwards explained.

the lower edge of the wedge, continued forward to the point of the coulter*. The uſe of it is to cut out, and raiſe up the under ſurface; while the coulter performs a like operation on the ſide. For this purpoſe, it is generally made up of two different forms, ſuited to the two different ſtates of a hard or a looſe ſoil. If the ſoil is of the firſt kind, the ſhare is made tapering in ſuch a manner, that its point paſſes nearly under the middle of the earth of the furrow; and conſequently deviates a little from the plane of the left ſide of the plough. The point is made tapering, becauſe by this form it penetrates more eaſily; and as the ſoil has great coheſion, by paſſing under the middle of the earth of the furrow, it raiſes up the whole.

The other form of this part of the plough is calculated for the looſe kind of ſoil, which has ſo little coheſion, that it cannot be moved by penetrating below any particular part of it, but almoſt the whole of it muſt be cut or ſcooped out, before it can be raiſed. To produce this effect, the point of

* See fig. 6.

of the ſhare lies in the plane of the left ſide of the plough, becauſe the greateſt reſiſtance muſt be on that ſide; and from the point it has a ſharp edge projecting towards the right, called the fin or feather of the ſhare, which penetrates below the earth of the furrow, and cuts it out.

I have been ſo minute in the deſcription of this inſtrument for two reaſons. The firſt is, that its manner of operation, and the effect of every part of its conſtruction, may be perfectly underſtood, ſo that any perſon may comprehend what form is neceſſary to lay the ſoil in the ſituation he ſhall judge moſt proper, and be enabled to give directions for making it accordingly.

The other reaſon is, to lay a foundation for the application of ſome theory, by ſhowing that the form and operation of the plough are reducible to mechanical principles, and that from them concluſions may fairly be drawn towards determining its moſt advantageous figure.

The beſt plough is certainly that which, all other circumſtances being equal, is pulled by leaſt force. But, if it ſhall happen, which

which may probably be found to be the caſe, that the plough which requires the leaſt force cannot have all other circumſtances equal, the next inquiry will be, how to form compenſations, ſo that the effect of theſe detrimental circumſtances may be felt as little as poſſible.

With a view to determine the firſt of theſe points, namely, the form of the plough moved by leaſt force, all the pains already taken to reduce it to the figure of a half wedge have been beſtowed. The deviations, though very conſiderable, were not ſo great as to invalidate any conſequences drawn from the one to the other; becauſe they changed a little the regular figure, without altering at all, or very little, the manner of operation; and it is evident that a change in the latter only can have any conſiderable effect upon the common concluſions. But, although the differences in figure ſhould have a greater effect than can reaſonably be ſuppoſed, yet they cannot be ſo conſiderable as to produce any material error in practice. It is ſurely not neceſſary to obſerve, that the common method of moving

moving the wedge by ſtrokes, at intervals, compared with the continued action that produces the motion of the plough, is no objection againſt the analogy between them, as the total ſum of the force requiſite to produce the ſame effect muſt in both caſes be equal.

The determination, then, of the form of the plough moved by leaſt force, ſeems reducible to this ſingle queſtion. Suppoſing any number of wedges of equal backs, but of different lengths, what is that particular length which meets with leaſt reſiſtance, in moving through ſuch a looſe ſubſtance as earth, the ſize and coheſion of whoſe particles are nearly equal?

I have ſuppoſed the backs of the wedges of equal thickneſs, becauſe the greateſt breadth of the ploughs compared together muſt be equal, as ſuch only can be imagined to do the ſame quantity of work in the ſame time. I have likewiſe ſuppoſed, that the ſize and coheſion of the particles of earth are nearly equal, both becauſe in drawing general concluſions all particular accidental circumſtances muſt be abſtracted from, and becauſe ploughed earth in ſome meaſure

meaſure approaches this ſtate, and does it the more, the higher it is cultivated, by being pulveriſed and cleared of obſtructions.

Now, it ſeems abundantly evident from theory, that, abſtracting from friction, the ſum of the reſiſtance which different wedges, whoſe backs are equally thick, meet with in ſeparating the parts of any ſolid body to the ſame diſtance, muſt be nearly the ſame. Theory teaches what common ſenſe indeed dictates, that the longer wedge requires leſs force to move it through the ſame ſpace; but this is a conveniency, or an apparent advantage only, and no ſaving of force upon the whole. Becauſe the longer wedge, in moving through the ſame ſpace, does not overcome an equal quantity of reſiſtence. In order to overcome the ſame reſiſtence, the longer wedge muſt move through a ſpace at leaſt as much greater than the ſhorter one, as the length of the former is greater than that of the latter. So that the gain of force upon the whole will be nothing, as the longer wedge loſes as much one way as it ſaves another*.

This

* From the theory of the wedge, the power is to the reſiſtence as half the back to one of the ſides; conſequently,

This is the case in cleaving wood, or any solid body, where all the resistence is generally accumulated on small portions of the opposite sides of the wedge. The circumstances are a little different; but the quantity of force will likewise be found to be equal, in moving wedges of different inclinations through such a loose body as earth. In this case, as before, the longer wedge meets the resistence more obliquely than the shorter; but, to counterbalance this advantage, the resistence acts a proportionally longer time *. For, supposing both wedges to move

consequently, if the back remain the same, while the side is increased, the resistance will be diminished in proportion. The side indeed does not increase quite so fast as the length of the wedge does; but, when the difference between the half back and the side is considerable, as in the present case, it will do so very nearly. Hence the resistence in the same space is diminished very nearly as the length increases. And as the whole space is greater in that proportion, the sum of the force in both cases will be equal.

* Let ABC, FHG, fig. 9. and 10. be two wedges of equal backs, AC, FG, but different lengths AB,

move with the same velocity, and consequently to lay off from the broadest part of them the same quantity of soil in the same time; yet the space of time that any particle acts against the longer wedge will be as much longer than the time it acts against the shorter, as the obliquity of the former is greater than that of the latter.

What has been proved of the whole wedge must hold equally true of the half one; for, abstracting as before from friction, the latter, in the same circumstances, must meet with exactly half the resistence of the former.

It seems to follow from this reasoning, that all ploughs which are of equal breadths, whatever their lengths be, should be pulled by equal force. This would certainly be the case, were the circumstances above mentioned the whole that should be taken into the account, or had the particles of earth, like those of some fluids, little or no friction among

AB, FH, the particles acting in the direction DE do it with a greater obliquity, or a smaller angle DEB, than the particles acting in the direction KL with the greater angle KLH; but the action of the former takes place along the longer line BE than HG.

mong themſelves, and very little againſt any ſolid body over which they move. But the particles of earth have a conſiderable friction among themſelves, and againſt any body over which they move; and therefore muſt conſiderably retard the motion of a body moving through them. Here, then, ſeems to be the circumſtance that muſt be deciſive of the form of the plough moved by leaſt force; for, it is plain, it muſt be the one that has the leaſt friction, or that removes the particles of earth to an equal diſtance with the leaſt rubbing upon itſelf.

Now, the plough that does this, muſt be the one that expoſes leaſt ſurface to the ſoil; for, the greater the ſurface, the greater always muſt be the quantity of particles that rub at the ſame time, and conſequently the greater the ſum of the friction.

To be perfectly ſatisfied of the truth of this propoſition, I made experiments by moving half wedges of different lengths, but of the ſame thickneſs at the back, through ſand. I cauſed make four half wedges, whoſe lengths were to one another as the numbers 3, 4, 5, 6. I computed pretty accurately

curately the ſurface of each of them, and found, that the weights that moved them were very nearly proportional to their ſurfaces *.

Theſe experiments are a proof, not only that friction is in proportion to the ſurface of the plough, but alſo eſtabliſh the preceeding theory; namely, that, abſtracting from this circumſtance, the reſiſtence made to all wedges of the ſame thickneſs, whatever their lengths be, is the ſame, in producing equal effects.

Now, of all wedges of equal backs, the ſhorter have always leſs ſurface. Hence follows this general concluſion: Of all ploughs of the ſame breadth, thoſe that

D have

* I put a quantity of ſand upon a large table, and then moved the wedges through it by a weight ſuſpended on a thread that run over a pully fixed on the edge of the table. I took all the care I could to bring the ſand into the ſame ſtate every time the wedges were pulled through it; and repeated the experiment many times, with very nearly the ſame reſult.

have the greater inclination, and consequently are ſhorter and expoſe leſs ſurface to the ſoil, are pulled by leſs force.

In confirmation of this doctrine, it may be obſerved from experience, that this is remarkably the caſe with the iron plough, which is univerſally allowed to be pulled by leſs force than any other. It has however diſadvantages that have hitherto prevented its general uſe, and probably will continue to do ſo; the only reaſon for mentioning it here, is the authority it affords in favour of the preceeding concluſion, which is ſo conſiderable, as not to have eſcaped the groſs obſervation with which things of this nature are generally attended to.

It was formerly hinted, that the plough pulled by leaſt force would probably be found to have diſadvantages, which, in ſome meaſure, counterbalance the advantages ariſing from this circumſtance. The chief of theſe is, that it moves unſteadily, and, on this account, performs its work more imperfectly.

The

The reaſon is, that, by being ſhorter, it moves upon a ſmaller baſe, and is much lighter in proportion; ſo that it is much more eaſily turned out of its direction, by any unequal exertion of the force, or extraordinary reſiſtance in the ſoil.

Experience will remove almoſt entirely any inconveniences proceeding from unequal exertions of the force. But it will be extremely difficult, if not impoſſible, to remove every extraordinary interruption in the ſoil. Cultivation, however, tends to remove theſe; and the more the ſoil is cultivated, the fewer of them will remain. What particular length of the plough is adapted to the various degrees of cultivation, it ſeems impoſſible to give any rules how to decide. This muſt be determined by experience and obſervation taken from circumſtances on the ſpot, with the help of the following general rule, ‘ that it ſhould be made as ‘ ſhort as poſſible’.

From this view of the ſubject, one might eaſily deduce the hiſtory of the old Scots plough, though otherwiſe entirely ignorant of it †. The whole conſtruction of this inſtrument marks its being intended for a ſoil in the moſt uncultivated ſtate, abounding with obſtructions of every kind. The great length of the part that moves below the ſurface, and the exceſſive ſtrength and weight of all its parts, plainly ſhow the great occaſion that the contrivers had to prevent its being turned aſide, or broken to pieces by the numerous and obſtinate interruptions to which it was expoſed. The elevation alſo of the hinder part of the mould-board, and the tapering of the ſhare, evidently imply a ſoil ſo hard, or ſo cloſely bound together by the roots of vegetables, as to riſe entire and unbroken.

The original contrivance of this machine might be extremely well adapted to the circumſtances in which it was firſt employed, and certainly is ſo ſtill to the ſituation in which it is generally uſed; but it ſeems improper to continue to employ it of the ſame ſize and weight, where the circumſtances that gave occaſion to that ſtrong and heavy conſtruction have no longer exiſtence, and in ſoils that have attained a conſiderable degree of cultivation.

From

† See fig. 7.

From the preceeding reaſoning it appears what form of the plough is moſt advantageous, ſuppoſing it a half-wedge, and that its properties are to be determined from the theory of that inſtrument. But perhaps it may be aſked, whether this is the beſt figure, and whether ſome other might not be attended with greater advantages? A ſuſpicion that this might be the caſe, ſeems to have given riſe to the curved mould-board, which has already been deſcribed.

The figure of a ſhip has alſo been quoted, and an analogy apprehended or imagined between the motion of it and that of the plough. It has been ſuppoſed, that earth in a ſtate of perfect cultivation approaches the nature of a fluid, and that the figure moſt proper for moving through water, is therefore beſt adapted for moving through ſoil.

It is evident, from what was formerly obſerved concerning the direction of the force that pulls the plough, that the reſemblance to the figure of a ſhip can only take place on the right ſide; and that the left ſide muſt infallibly be plain, becauſe in this form only ly can the direction of the plough coincide with the direction of the force. The matter then is reduced to this question, 'Whether 'the right side of the plough can admit of 'any curved figure, that meets with less re-'sistence and performs work as well, or better 'than the plain?'

That no curved figure can meet with so little resistence as the plain, supposing always the greatest breadth in both cases the same, even in moving through a fluid of very little tenacity or friction, seems abundantly evident from this single consideration, that it must constantly drive the fluid more before it. The plain allows the fluid to slide easily along its surface, and consequently meets with less resistence; but the least curve or bending † above the plain must more or less repel the particles towards the parts from which they came, or in the direction in which the surface moves, and therefore be exposed to proportionally greater resistence.

This

† See fig. 7.

This is obviously the case in the motion of a ship of the sharpest bow; and there can be no question, if the fore-part of a ship were made in the figure of a wedge, it would meet with less resistence than in any curved figure of which it can be formed. But such a ship would be altogether unfit for the purposes of navigation; for she could bear very little sail, and the least hard gale would run her down. This is the reason why ships with the broadest bows are the safest, though the worst sailers.

The resistence made to the plain figure will be still proportionally less in moving through such a body as earth, whose particles have a considerable friction and cohesion. The curved figure, in this case, besides pushing the particles before it, must be exposed to more friction, as its surface is larger; for it is evident that the least curve must make the surface greater than if it were plain.

To prove experimentally what has been advanced, I procured a half-wedge of the same greatest breadth with those formerly mentioned, but rising on the right side with a

gentle

gentle curve. I found that it always turned aside to the left of the direction of the force, pushed the sand more before it than the plain half-wedge, and was resisted in a considerably greater proportion than that of its surface. Hence it appears, that the wedge is the figure that meets with least resistence, and consequently that the curved mould-board requires more force to pull it than the plain †.

There seems also to be great reason to doubt, whether the curved mould-board performs better work than the plain. That it bruises and separates the soil more, must be admitted; but in the naturally loose earth, wherein it must be used, this can be performed

† It will perhaps be objected here, that this doctrine contradicts what Sir Isaac Newton has advanced concerning the solid of least resistence; which is well known to be different from the wedge. But in answer, I beg leave to observe, that that solid is a mere jeu d'esprit, which presented itself to its great author in the course of other inquiries, which neither he, nor any body since his time, has attempted to apply to any use, and which probably never can be applied to any, at least it cannot to the present subject.

formed very easily by another instrument of agriculture, and when land is ploughed for fallow, the more it is broken the worse. It may be said indeed, that this board might be applied to the plough constructed for a soil that rises entire, where it would be of singular use in breaking and reducing it. But this is what has never been thought proper to be put in practise: And indeed it seems very uncertain whether a soil that rises entire, could be broken by any curve of the mould-board, that would not render this machine intolerably hard to draw, from its natural figure, already extremely heavy and difficult to move.

Hitherto I have described the figure of the plough, and explained its manner of operation; I have investigated the properties of it; and endeavoured to determine its most advantageous form: It only remains, that I point out the principles on which the position and proportions of its particular parts depend, especially those of the beam and handles.

The beam is entirely subservient to the purpose of moving the plough; its position, therefore, and dimenſions muſt be determined by the ſtructure of the machine it moves, and the direction of the force that acts upon it, which are the only circumſtances that can affect it.

If a wedge were driven into any body whoſe preſſure and friction are equally diſperſed over the ſides of the wedge, common ſenſe and experience dictate, that, to move it ſtraight forward, the force muſt be applied, as near as poſſible, to the middle of its back. But, if the preſſure and friction are not equally diſperſed, or take place more towards one ſide of it than the other; then the force muſt be applied on the back, as much nearer that ſide as the preſſure and friction on it are greater. All which in theory means no more than this, that, to move the wedge ſtraight forward, the force muſt be applied ſo as to move the center of reſiſtence * in that direction.

In

* The center of gravity, is the point at which all the weight of a body may be ſuppoſed accumulated, on its being ſuſpended. The center of reſiſtence,

In the ſame manner, if a wedge were moved through ſand, or ſuch a body as earth, on one of its edges, and had more preſſure or friction on its lower than its higher parts, to make it hold a horizontal direction, the force behoved to be applied on its back, as much lower than the middle, as the reſiſtence on that ſide is greater. Now, if inſtead of the force applied to its back, it were pulled forward by an equal force applied to its face, this force muſt act in a horizontal line beginning from its center of reſiſtence. Hence it appears, that, were the plough a perfect half-wedge, the only direction of the force that could move it ſtraight forward, would be a horizontal one, paſſing as much below the ſurface of the ſoil as this center is ſituated below it; and that a direction ſo much above this, as

that

reſiſtence, is a point at which is accumulated all oppoſition to its motion forward. This oppoſition ariſes from the inertia of the body itſelf, and the reſiſtence and friction of other bodies. The center of reſiſtence will always approach that ſide on which the obſtructions are greater.

that of animal force muſt unavoidably be, would very ſoon bring it out of the ground altogether.

To prevent this laſt conſequence, the plough is ſo formed as to have a conſtant tendency to penetrate deeper into the earth, which it acquires chiefly by the inclination of the coulter; and from this circumſtance ariſes the neceſſity of an upward direction of the force, to balance the downward tendency of the machine, and the convenient application of animal force in order to pull it.

The proper line, then, of force that moves the plough, ſhould begin from its center of reſiſtence, with ſuch a direction upwards, as juſt to balance the tendency of the machine downward; for in this caſe only can the motion be performed ſtraight forward.

Now, this line, it is evident, in coming upward from the center of reſiſtence, behoved to paſs through the firm ground before the plough *, and cut a paſſage for itſelf

* Suppoſe C, fig. 8.] the center of reſiſtence, CD the line of draught; the real line, if there is only one force applied, but the mean line, if two, found by biſecting the angle which the directions of the two forces make with one another; without a team, this line CD muſt have been fixed at C, below the ſurface of the earth KH; ſo that the ſurface of the ground would have interfered with the direction of it. This is prevented by the point of the beam that takes up this line at E, as near the ſurface of the earth as poſſible. So that the point of the beam lies in the line of force paſſing to the center of reſiſtence.

ſelf as it moved along, a thing at firſt ſight utterly impracticable. But the ſame purpoſe is anſwered by the beam, as if what has been obſerved were really poſſible; and this is the circumſtance that determines all at once both its uſe and length. For the beam muſt be ſo placed, and be of ſuch a length, as to coincide with a point of this line of direction, at a convenient height above the ſurface of the ground, and by taking it up here, ſuperſede the neceſſity of its being continued farther down; ſo that the effect is perfectly the ſame as if the force acted on a line coming directly from the center of reſiſtence.

The beam muſt be ſituated at a convenient

ent height above the surface, to avoid the interruptions to which it might otherwise be exposed; and therefore, supposing the downward tendency of the plough determined, and the upward direction of the force necessary to balance it, the beam must be made longer or shorter, till its point fall into a point of the height required in the inclined line of the force. Now, the greater the downward tendency, the more upward must be the direction of the force; and, consequently, the sooner must the beam meet with it, that is, must be the shorter. On the other hand, the less downward the tendency, the less upward will be the direction, and the farther must the beam be extended before it meets with that line, and consequently will be the longer.

This doctrine would be exactly conformable to fact, and the ploughs with the more inclined coulters would always have the shorter beams, and those with the less inclined ones the longer, were it not that the direction of the force may easily be changed, by yoking the cattle nearer or farther from the point of the beam. Hence it happens,

pens, that a plough may have a great downward tendency, and also a long beam, and the effect of both counterbalanced, by placing the cattle very near, which will give a great upward direction to the force. On the other hand, a plough may have a small inclination and short beam, and notwithstanding have downward tendency enough, by placing the cattle at a considerable distance, which will give a less upward direction to the force. Since, then, these circumstances may be, and always are made to counterbalance one another, it will be asked, perhaps, whether it is of any consequence in what manner they do it, and whether there are any principles that determine exactly the best length of the beam, the most proper inclination of the coulter, and the most advantageous position of the cattle?

With regard to the beam, it should be made as short as possible; because the shorter it is, it will be much lighter in proportion, without being more in hazard of breaking, the only danger to which it is exposed. A beam is plainly a lever, on which consequently the longer it is, the force tending to break

break it must act with greater advantage; and as the weight of adherent bodies equally strong increases much faster than their length *, the shorter beam will be equally strong and much lighter at the same time.

The longer beam, however, has one advantage over the shorter, which is, that it contributes more to make the motion steady, and this it does by being a longer lever.

Any extraordinary interruption must put all the parts of the plough in some measure

* Similar solids, and such only can be equally strong, are to one another as the cubes of their lengths. [Euclid b. 12. prop. 2. M'Laurin's account of Sir I. Newton, p. 170.] Suppose two bodies, whose lengths are as 2 and 3. The cubes of these numbers, are 8 and 27. Which last numbers, if the bodies are of the same kind of matter, will express their different weights. Hence it appears, if the length of a body be increased only in the proportion of 2 to 3, its quantity of matter must be augmented so much, to make it equally strong as before, that its weight becomes three times and near a half greater. This is the reason that the larger animals of a kind are not stronger in proportion to their size than the smaller, because their quantity of matter does not increase so fast as their bulk. If it did, they would be rendered perfectly unwieldy and a burden to themselves.

measure out of their proper direction, and those most that are at the greatest distance from the center; consequently, an obstruction that moves the share only a very little up or down, will make the point of the beam describe a large portion of a circle. But the longer beam, by describing a larger portion than the shorter one, will be sooner resisted, by the direction of the force, and, therefore, sooner brought back to its proper position; so that the same obstruction will less disturb the motion of the plough with the longer beam, than the one with the shorter.

But, unless the interruptions are numerous and obstinate, this circumstance cannot be of much moment; because the greatest difference in length cannot be very considerable.

Here also it appears, that, by means of the beam, the plough acquires a more steady and equal motion than if it were pulled by a line running directly to the center of resistence. For, in the latter case, the direction of the force could not have contributed

any

any thing to correct the effect of obstructions, which always must be done more or less by the intervention of the beam.

Now, the way to have the shortest beam, is to place the point of it as near the surface of the ground as possible; for this plain reason, that, whatever the direction of the force be, the lower the beam is set, they must the sooner coincide. What the height of the point of the beam should actually be, it is impossible to decide in general, because it must be different in different circumstances; and every person must determine for himself, from the situation of the surface he has to cultivate. I have specified the point of the beam, as it is the part of it that can meet with any interruption; for custom has very properly formed it farther back into a considerable curve, to prevent the plough from being incommoded, or choaked up by stubble, or any loose thing collected by the inclination of the coulter.

With respect to the inclination of the coulter, I have already illustrated the superiority of this position to a perpendicular one; and am now to inquire, whether there is

is any one inclination preferable to another. This question seems easily decided; for the most advantageous inclination is certainly the one that is exposed to least resistence; but the one exposed to the least resistence is the greatest, because it meets the resistence at the greatest obliquity; and hence it seems evident, that ploughs with most inclined coulters should be most easily drawn.

This consequence would certainly follow, if the inclination of the coulter had no effect upon the last mentioned circumstance, the direction of the force; or if it were indifferent to the cattle, whether they pull more or less horizontal. But it is by no means indifferent to the cattle, in what direction they pull; for the most advantageous one is plainly very near to horizontal †. The reason

* Cattle pull with most effect in a horizontal line passing through their center of gravity. If they are obliged to pull from a point above or below this center, they must bend their bodies from their natural and most easy position, till they bring their center into their line of draught. The horizontal direction allows

reaſon is, that, by pulling in this manner, their whole force is employed in promoting motion in the direction in which themſelves move; whereas, in pulling either upward or downward, they act obliquely to the direction forward; and conſequently part only of their force can be exerted in that direction; and this part will be proportionally ſmaller, the more upward they pull. Hence then it follows, as the greater the inclination of the plough, the more upward always muſt the cattle pull, that all the advantage gained by the inclination is loſt by the direction of the force, and that, on the whole, no one inclination is preferable to another. The only exception to this general concluſion is the caſe of land in a low ſtate of cultivation, infeſted with ſtrong roots of vegetables, which will ſlide more readily on the face of the coulter the more it

allows them to act in the moſt natural and eaſy poſition. Beſides, it is the horizontal direction that promotes motion forward; for, if they pull upward or downward, a part only of their force can be employed in the horizontal direction, as is plain from the reſolution of forces.

it is inclined; for which thoſe who have a ſoil in this ſtate to cultivate, muſt make an allowance.

The uſe of the handles, is to regulate the motion of the plough. If the downward tendency of the coulter and the upward direction of the force were exactly balanced, and the reſiſtence of the ſoil uniform, there would be very little occaſion for handles, becauſe there would be nothing to turn the plough from the right direction. But, as it is extremely difficult to have matters ſo nicely adjuſted as now ſuppoſed, even though the beam and coulter are made moveable by wedges from their original poſition, till an equilibrium takes place; and as it is impoſſible, that the reſiſtence of the moſt cultivated ſoil can be uniform, the handles become neceſſary to correct any little defect in the original conſtruction, and to apply an immediate remedy to any deviation ariſing from extraordinary interruptions. For this purpoſe, they act as levers, which may be conſidered as beginning from the center of reſiſtence; and it is evident, that the longer they are, they have the greater

greater power, and the ſhorter the leſs. Their beſt length and height will be thoſe which allow them to be moſt eaſily and conveniently managed, or which oblige the perſon that holds them to bend his body as little as poſſible. In this view, their height muſt be ſuited to their ſize and their length to his ſtrength. If the ſoil be in a tolerable ſtate of cultivation, and the machine well conſtructed, they will not need to be very long; and the ſhorter they are, provided the perſon that holds them have ſtrength enough to manage them, the better; for he will be obliged to bend his body leſs to produce the ſame effect.

As I have ſaid, the handles may be conſidered as levers beginning from the center of reſiſtence, it will perhaps be aſked, Whether this is, in all caſes, ſtrictly true; and how we ſhall be able to decide, whether it is ſo or not? To do this accurately, we ſhould be determined exactly with regard to the ſituation of the center of reſiſtence. But the truth is, this determination cannot be made by any principles or operation previous to actual trial; becauſe it depends upon the friction and reſiſtence of the ſoil, which muſt vary

vary conſiderably according to circumſtances.

Could this center be accurately found, a plough might be conſtructed at once, that would perform its work perfectly, without further alteration; and there would be no neceſſity to leave the principal parts in a ſtate moveable by wedges to obtain their true poſition. In working, however, this center may be very nearly determined; becauſe it will always be found in the line of direction of the force produced downward from the point of the beam; and we may be aſſured this line paſſes through the center, when it exactly balances the inclination of the coulter. But, before application to uſe, the ſituation of the center can only be gueſſed at, which, indeed, by the aid of experience in ſimilar caſes, may be done with a good deal of accuracy; at leaſt, ſo accurately, that a ſmall alteration in the poſition of the beam, which is left practicable on purpoſe, will remove the bad effect of any error that may be committed in the conſtruction.

This center will commonly be found a few inches above the middle of the ſhare, though,

though, in particular cafes, it will be higher or lower according as the refiftence is greater on the furface, or at the bottom of the furrow: And this is the reafon why the fame plough, though made with the greateft exactnefs, will go too deep in fome cafes, and in others too fhallow. It was becaufe the fituation of this point may be nearly gueffed at, that I fuppofed it formerly actually found, and applied it to the determination of the length of the beam.

Now, in fome cafes, the greater handle is not ftreight, and does not go directly towards the center, but is curved downwards, and joined to the hinder part of the head, or fhare: In others, it is almoft ftreight, and feems to go directly to the center. The only circumftance that determines the fuperiority of one of thefe forms above the other, is its being a longer lever than the other; that is, the diftance of the extremity of the one from the center being greater than that of the other; for, according as this diftance is greater, equal, or lefs, their powers will be fo likewife. It muft not be imagined, becaufe

becaufe the * crooked handle is longer in itfelf than the ftreight one, that therefore it is more advantageous. This feems rather a difadvantage; becaufe, the longer it is, it will be the lefs able to bear the fame preffure.

It only remains that I make fome obfervations on the length and pofition of the fheat. The chief ufe of it, is to connect all the parts of the plough together; and, in this view, the fhorter and more inclined it is, it muft be the ftronger.

Its proper length will be determined by the depth of the furrow intended to be made; for its length muft be always as much greater than that depth, as will allow the point of the beam to move at a convenient height above the furface. Longer, however, it needs not be; and it fhould never be made longer than is neceffary; for a fmall addition to the length will make it fuffer much more in point of ftrength, than in proportion to that addition. It muft be obferved, that what has now been faid of the length of the fheat, refpects only its perpendicular height, not its actual length, as meafured

* See fig. 5.

fured in the inclined pofition in which it generally ftands.

The reafon why the fheat is inclined rather than perpendicular, is not fo much, that thereby it fuftains lefs ftrefs, but becaufe it is more able in this pofition to bear it; for, by being inclined, it acts in fome meafure lengthways againft the ftrefs, which it muft do wholly laterally when perpendicular; and it is very obvious, that there is a very great difference in the ftrength in thefe two fituations.

If the foil, however, is not very uncultivated, there will be no need of a great inclination, becaufe the ftrefs will not be very confiderable; and, as the earth of fuch a foil will be in fome meafure loofe, the lefs the inclination, there will be lefs fpace between the coulter and the fheat, which will prevent the earth falling to the left fide of the plough; a confequence very ready to follow when the inclination is great.

Though it feems proper that the fheat fhould be nearly parallel to the coulter, it fhould be rather nearer it above than below, becaufe the upper part of the foil being higher

higher raifed, will be more broken, and therefore more apt to fall to the left, unlefs prevented by having lefs fpace.

I fhall finifh this fubject, by making fome obfervations on the Wheel-plough, which has of late come into ufe, efpecially among thofe who are called *improvers*: For which reafon it will not be improper to inquire a little into its merits.

The chief, or indeed the only advantage this kind of plough has over another of a proper form for anfwering the fame ends, is, that the wheels keep the beam conftantly, or very nearly, at the fame height, which caufes the furrow to be uniformly deep; whereby are prevented all the inconveniencies arifing from the irregular action of the cattle, and the ignorance or inattention of the ploughman.

It is very plain, that this advantage is gained only on level ground, cleared of ftones and obftructions: For, if the furface be in any degree uneven, the wheels counteract the very purpofe for which they are employed, and render it impoffible for the ploughman to adapt his management to the rifing rising or falling of the surface, which he may do with a plough of another form. If the wheels are suddenly raised by stones, a rise of the surface, or even by clods, or the tilled ground, that instant the plough must be thrown out of the earth, by the beam being lifted up along with the wheels on which it rests; so that the depth of the furrow must be raised, and the soil improperly stirred: And this inconvenience must remain while the interruption continues, and be repeated as often as a like interruption occurs. Besides all this, in such finely cultivated flat soil, wherein only this plough can be used with advantage, it is no difficult matter for a very ordinary ploughman, with a common plough, to form a furrow, so well shaped in every respect, that it will require a considerable degree of attention to distinguish it from one made with the wheel-plough, and will make no descernible difference on the crop.

On the other hand, the disadvantages of this plough are abundantly manifest. It is, in the first place, very complex, which, all other

other circumstances being equal, is a draw-back on all kinds of machinery, especially such as, like the present, must come into unskillful hands, who have neither much attention to prevent, nor much dexterity to rectify, its disorders. It is, in the next place, very expensive in the original purchase, and correspondently so in its repairs: Neither can it be supposed to last very long, on account of the complication of its construction, the slender make of many of its parts, and their being constantly exposed to all the severities of the weather.

But its chief disadvantage is, that it is much heavier to draw than a plough of the common construction. The actual resistence from the furrow will be nearly equal: The handles, indeed, in the wheel-plough, are somewhat lighter; but this will produce little odds to the cattle. All the resistence, consequently, arising from the wheels, and all the machinery about them, is pure additional load upon the motion. If it be considered, that the diameter of the wheels is commonly very small, that there is a very con-

considerable weight of naturally heavy materials upon them, added to the pressure of the beam, we may conclude, that the friction of the wheels must be very considerable. It would be a great diminution of this friction, if the diameter of the wheels were made double or triple in length what it is at present, which would diminish the friction in the inverse proportion: But this alteration would render it very inconvenient, if not impossible, to turn the plough.

The only counterbalance I can figure in the common plough to these disadvantages, is, that the downward tendency of the machine requires a weight to be laid on the backs of the hindmost cattle, which is not necessary in the wheel-plough; because this weight is supported by the wheels.

I cannot easily estimate the amount of this disadvantage; because it varies at different times, according to the hardness, the stiffness, or dirtiness of the soil; but, from experience, it seems not to be very considerable; for the obliquity of the direction that produces it is not very great, and the cattle exposed

exposed to it do not seem very sensibly to be wasted by it. The wheel-plough, then, seems exposed to several certain disadvantages, without being possessed of one real indisputable advantage.

F I N I S.

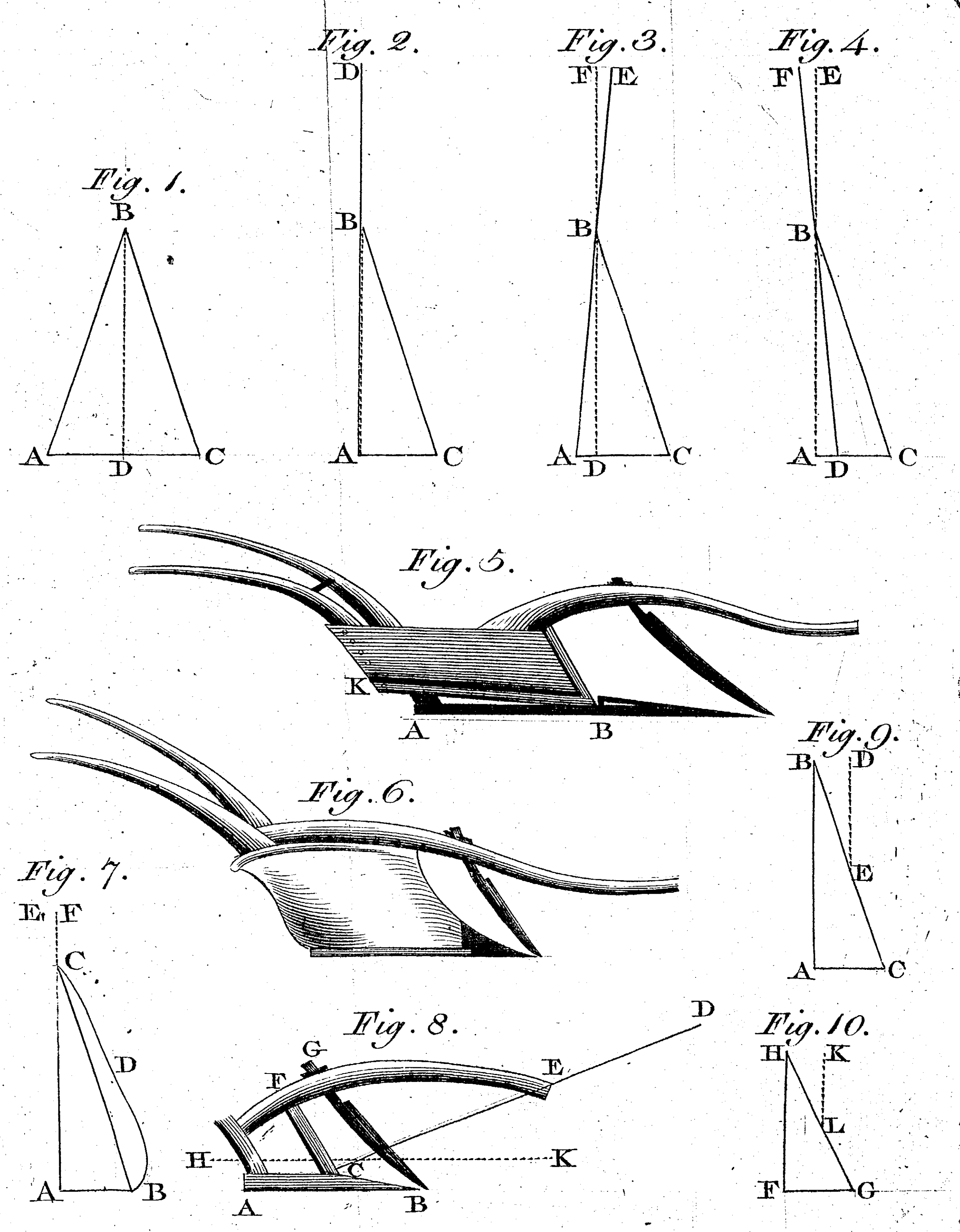
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Fig. 10.
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