II. *Observations on horizontal Refractions which affect the Appearance of terrestrial Objects, and the Dip, or Depression of the Horizon of the Sea. By* Joseph Huddart, *Esq. F. R. S.*

Read November 24, 1796.

The variation and uncertainty of the dip, in different states of the air, taken at the same altitude above the level of the sea, was the occasion of my turning my thoughts to this subject; as it renders the latitude observed incorrect, by giving an erroneous zenith distance of a celestial object.

I have often observed that low lands and the extremity of head lands or points, forming an acute angle with the horizon of the sea, and viewed from a distance beyond it, appear elevated above it, with an open space between the land and the sea. The most remarkable instance of this appearance of the land I observed at Macao, for several days previous to a typhoon, in which the Locko lost her topmasts in Macao roads; the points of the islands and low lands appearing the highest, and the spaces between them and the sea the largest, I ever saw. I believe it arises, and is proportional to the evaporation going on from the sea; and in reflecting upon this phænomenon, I am convinced that those appearances must arise from refraction, and that instead of the density of the atmosphere increasing to the surface of the sea, it must decrease from some space above it; and that evaporation is the principal cause which prevents the uniformity of density and refraction being continued, by the general law, down to the surface of the earth: and I am inclined to believe, though I mention it here as a conjecture, that the difference of specific gravity in the particles of the atmosphere may be a principal agent in evaporation; for the corpuscles of air, from their affinity with water, being combined at the surface of the fluid from expansion, form air specifically lighter than the drier atmosphere; and therefore float, or rise, from that principle, as steam from water; and in their rising (the surrounding corpuscles from the same cause imbibing a part of the moisture), become continually drier as they ascend, yet continue ascending until they become equally dense with the air.* However, these conjectures I shall leave, and proceed to the following observations upon refractions.

In the year 1793, when at Allonby, in Cumberland, I made some remarks on the appearance of the Abbey Head, in Galloway, which in distance from Allonby is about seven leagues; and from my window, at fifty feet above the level of the sea at that time of tide, I observed the appearance of the land about the Head as represented in Tab. I. fig. 1. There was a dry sand, *x y*, called Robin Rigg, between me and the Head, at the distance from my house of between three and four miles, over which I saw the horizon of the sea, H O; the sand at this time was about three or four feet above the level of the sea.

* Mr. HAMILTON, in his very curious Essay on the Ascent of Vapours, does not allow of this principle, even as an assistant; though by a remark (page 15) he takes notice of those appearances in the horizon of the sea, and says they arise from a strong or unusual degree of refraction; the contrary of which I hope to illustrate in the course of this paper.

The hummock *d* is a part of the head land, but appeared insulated or detached from the rest, and considerably elevated above the sea, with an open space between. I then came down about twenty-five feet, when I had the dry sand of Robin Rigg, *x y*, in the apparent horizon, and lost all that floating appearance seen from above, and the Abbey Head appeared every where distinct to the surface of the sand; this being in the afternoon, the wet or moisture on the sand would in a great measure be dried up. I have reason, therefore, to conclude that evaporation is the cause of a less refraction near the surface of the sea; and when so much so as to make an object appear elevated wholly above the horizon, (as at *d* in fig. 1.) there will from every point of this object issue two pencils of rays of light, which enter the eye of the observer; and that below the dotted line A B (parallel to the horizon of the sea H O), the objects on the land will appear inverted.

To explain this phænomenon, I shall propose the following theory, and compare it with the observations which I have made. Suppose H O, fig. 2. to represent the horizontal surface of the sea, and the parallel lines above it, the lamina or strata of corpuscles, which next the fluid are most expanded, or the rarest; and every lamina upwards increasing in density till it arrive at a maximum (and which I shall in future call the maximum of density) at the line D C, above which it again decreases in density *ad infinitum.*

Though this in reality may be the case, I do not wish to extend the meaning of the word density farther, than to be taken for the refractive power of the atmosphere; that is, a ray of light entering obliquely a denser lamina to be refracted towards a perpendicular to its surface; and in entering a rarer lamina, the contrary; which laminæ being taken at infinitely small distances, the ray of light will form a curve, agreeable to the laws of dioptrics.

In order to establish this principle in horizontal refractions, I traced over various parts of this shore at different times, when those appearances seemed favourable, with a good telescope, and found objects sufficient to confirm it; though it be difficult at that distance of the land to get terrestrial objects well defined so near the horizon, as will afterwards appear.

One day observing the land elevated, and seeing a small vessel at about eight miles distance, I from my window directed my telescope to her, and thought her a fitter object than any other I had seen for the purpose of explaining the phænomena of these refractions. The telescope was forty feet above the level of the sea. The boat's mast about thirty-five feet, she being about twenty to thirty tons burthen. The barometer at 29,7 inches, and FAHRENHEIT's thermometer at 54°.

The appearance of the vessel, as magnified in the telescope, was as represented in fig. 3, and from the mast head to the boom was well defined. I pretty distinctly saw the head and shoulders of the man at the helm; but the hull of the vessel was contracted, confused, and ill defined: the inverted image began to be well defined at the boom (for I could not clearly perceive the man at the helm inverted), and from the boom to the horizon of the sea the sails were well defined, and I could see a small opening above the horizon of the sea, in the angle made by the gaff and mast; and had the mast been shorter by ten feet (to the height of *y*), the whole would have been elevated above the horizon of the sea, and from *y* to *d* an open space. This drawing was taken from a sketch I took at the time, and represents the proportion of the inverted to the erect object, as near as I could take it by the eye, the former being about two-thirds of the latter in height, and the same breadth respectively; though at one time during my observation, which I continued for about an hour, I thought the inverted nearly as tall as the erect object. The day was fine and clear, with a very light air of wind, and I found very little tremor or oscillation in viewing her through the telescope.

I have laid down fig. 4. for the explanation of the above phænomena, in which A represents the window I viewed B the vessel from; H O, the curved surface of the sea; C D parallel to H O, the height of the maximum of density of the atmosphere; the lines marked with the small letters *a a*, *b b*, *c c*, *d d*, the pencils of rays under their various refractions from the vessel to the eye, or object glass of the telescope.

The pencil of rays *a a*, from a point near the head of the mainsail, is wholly refracted in a curve convex upwards, being every where above the maximum of density; and the pencil of rays *d d*, which issues from the same point in the sail, and passes near the horizon of the sea at *x*, is convex upwards from the sail to W, where it passes the line of maximum of density, which is the point of inflection; there it becomes convex downwards, passing near the horizon at *x* to *y*, where it is again inflected, and becomes convex upwards from thence to the eye. The pencil of rays *b b*, from the end of the boom, passing nearly parallel to the horizon, and near the maximum of density, suffers very little deviation from a right line in the first part; but in ascending (from the curvature of the sea) will be convex upwards to the eye. The pencil of rays *c c*, from the same point in the boom, may have the small part to *c* convex upwards, from *c* to *z* it will be convex downwards, and from *z* to the eye convex upwards.

From this investigation it appears, that two pencils of rays cannot pass from the same point, and enter the eye, from the law of refraction, except one pencil pass through a medium which the other has not entered; and therefore the maximum of density was below the boom, and could not exceed ten feet of height above the surface of the sea at the time these observations were made.

Respecting the hull of the vessel being confused, and ill defined in the telescope, as by fig. 3, it arises from the blending of the rays, from the different parts of the object, refracted through the two mediums; some parts of the hull appearing erect, and some inverted. Suppose the dotted line *ii*, fig. 4, an indefinite pencil of rays, passing from between the inverted and erect parts of the object, or the upper part of the hull of the vessel, to the eye, (for the lower part of the hull could not be observed): the objects cannot appear inverted, except the angles at the eye *a*A*c* and *a*A*d*, exceed the angle *a*A*i*; for the intermediate space could only be contracted by the secondary pencils of rays. The lengths of the inverted, compared with the erect image of the sail, is as the sines of the angles at the eye *a*A*i* to *i*A*d*; and the angle at the eye *a*A*d*, made by the two pencils of rays from the same point near the head of the sail, must be double the angle *a*A*i*, when the inverted image is as tall as the erect. In this case, the sines of the angles *a*A*b*, *a*A*c*, *a*A*d*, fig. 4, are proportional to the altitudes *a b*, *a c*, *a d*, in the magnified view of the vessel, fig. 3.

Under this consideration no inverted image of the sail will be formed, until the angle at the eye, made by the two refracted pencils of rays *a a* and *d d*, exceed the angle made by *a a*, and *b b*, the apparent height of the sail of the vessel; for were those angles equal, the inverted sail would only be contracted into the parallel of altitude of the boom *b*, and render the appearance confused, as in the hull of the vessel.

Respecting the existence of two pencils of rays entering the eye from every point of an object not more elevated than *a*, or less than *i*, fig. 3, in this state of the atmosphere, I cannot bring a stronger proof than that of the strength of a light when the rays pass near the horizon of the sea, proved by the following observations.

Going down Channel about five years ago in the Trinity yacht, with several of the elder brethren, to inspect the light-houses, &c. I was told by some of the gentlemen, who had been on a former survey, that the lower light of Portland was not so strong as the upper light, at near distances, but that at greater distances it was much stronger. I suspected that this difference arose from the lower light being at or near the horizon of the sea, and mentioned it at the time; but afterwards had a good opportunity of making the observation. We passed the Bill of Portland in the evening, steering towards the Start, a fresh breeze from the northward and clear night; when we had run about five leagues from the lights, during which time the upper light was universally allowed to be the stronger, several gentlemen keeping watch to make observations thereon, the lower light, drawing near the horizon, suddenly shone with double lustre. Mr. STRACHAN, whose sight is weak, had for some time before lost sight of both lights, but could then clearly perceive the lower light. I then went aloft, (as well as others,) but before I got half mast up, the lower light was weaker than the upper one; on coming down upon deck, I found it again as strong as before. We proceeded on, and soon lost the lower light from the deck; and upon drawing the upper light near the horizon, it like the former shone exceeding bright. I again went aloft, when it diminished in brightness; but from the mast head I could then see the lower light near the horizon as strong as before. This is in consequence of the double quantity of light entering the eye by the two pencils of rays from every point. To illustrate which, we compare the vessel, fig. 4, to a lighthouse built upon the shore, and A the place of the observer; and having brought down the light so low as to view it in the direction *a a*, another light would appear in the horizon at *x* from the pencil *d d;* and had the vessel been still enough to have observed it at this time with a good glass, I doubt not but the two images might have been distinctly seen: as the light dropped, (by increasing the distance) the two images would appear continually to approach each other, till blended with double light in one, and disappear at the altitude *i*, above the apparent horizon of the sea. But, as explained before, if the strength of evaporation did not separate by refraction the pencils *a a* and *d d* to a greater angle than double the angle that the lamps and reflectors appear under, the two images would be blended, and the strong appearance of light would be of shorter duration. The distance run from the lights, during the time each of the lights shone bright, would have been useful, but this did not occur at the time, nor have I had the like opportunity since. However, I recommend to the mariner to station people at different heights in looking out for a light, in order to get sight of it near the horizon, when it is always strongest.

Respecting the appearance of the Abbey Head before mentioned, fig. 1, the dotted line A B represents the limit, or the lowest points of the land that can be seen over the sea; for, as above stated, all the objects appearing below this line, are the land above it inverted; and where the land is low, as at *d* and *m*, it must appear elevated above the horizon of the sea.

In fig. 5. let H O represent the curve of the ocean, and *d* the extreme top of the mount visible at A by the help of refraction; the dotted pencil of rays *c c* passing from *d* to the eye in some part a little below the maximum of density, where inversion begins; therefore no land lower than this can be seen; for any pencil from a point in the land lower than this, must in the refraction have a contrary flexure in the curve, and therefore pass above the observer. Let A D be a tangent to the curve at A, then the object *d* will appear to be elevated by refraction to D; also let A *v* be a tangent to the pencil A *x* at A, then the angle D A *x* will appear to be an open space, or between D and the horizon of the sea. Suppose a star should appear very near and over the mount *d*, as at *, two pencils would issue from every point of it, and form a star below as well as above the hummock *d*. There are always confused or ill defined images of the objects at the height of the dotted line, fig. 1, above the level of the sea, as before mentioned; and instead of the points of *d* ending sharp in that line, they appear blunted, and the Abbey Head is frequently insulated at the neck *m*.

I have viewed, from an elevated situation, a point or head land at a distance beyond the horizon of the sea, forming, as in fig. 6. a straight line A B, making an acute angle B A O with the horizon of the sea. Seeing the extreme point blunted and elevated, I descended; and though in descending the horizon cut the land higher, as at H O, H O, yet the point had always the same appearance as *a, a, a,* fig. 6, though the land is known to continue in the direction of the straight line A B to beneath the horizon, or nearly so, as viewed from the height above.

If then from a low situation we view this head land through a telescope, the inclination of the surface A B to the horizon being known to be a straight line, it will appear as in fig. 7. the dotted line (at the height of the point where a perpendicular *x y* would touch the extreme of the land) being at the limit or lowest point of erect vision. And if a tangent to the curved appearance of the land *a b*, is drawn parallel to the inclined surface of the land A B, fig. 6, touching it at C, the point C will shew the height of the maximum of density, where the pencil of the rays of light, from thence to the eye, approach nearest the sea; for pencils of rays from this land, taken at small distances from C, will form parallel curves, nearly, through the refracting mediums, and C will be the point of greatest refraction; for above C as at B the refraction somewhat decreasing, will appear below the line *a b*, or the parallel to the surface of the land, and the refractions decrease below the point C; for had they increased uniformly down to the surface of the sea, it would render the apparent angle of the point of land *z* more acute than the angle C *a* O, contrary to all observations.

Thus I have endeavoured to explain the phænomena of the distorted appearance of the land near the horizon of the sea, when the evaporation is great; and when at the least, I never found the land quite free from it when I used a telescope; and from thence infer, that we cannot have any expectation to find a true correction for the effect of terrestrial refraction, by taking any certain part of the contained arc; for the points *z* C B, fig. 7, will have various refractions, though they are at nearly the same distance from the observer. And if the observations are made wholly over land, if the ground rises to within a small distance of the rays of light in their passage from the object to the eye, as well as at the situation of the object and observer, the refractions will be subject to be influenced by the evaporation of rains, dews, &c. which is sufficiently proved by the observations of Colonel WILLIAMS, Captain MUDGE, and Mr. DALBY, Phil. Trans. 1795, p. 583.

The appearances mentioned by Colonel WILLIAMS, Captain MUDGE, and Mr. DALBY, (Phil. Trans. 1795, p. 586, 587,) cannot be demonstrated upon general principles, as they arise from evaporation producing partial refractions. In those general principles, it is supposed that the same lamina of density is every where at an equal distance from the surface of the sea, at least as far as the eye can reach a terrestrial object; but in the partial refractions, the lamina of the expanded or rarefied medium may be of various figures according to circumstances, which will refract according to the incidence of the rays, and affect the appearance of the land accordingly, which I have often seen to a surprising degree. But my principal view is to shew the uncertainty of the dip of the sea, and that the effect of evaporation tends to depress the apparent horizon at x, when the eye is not above the maximum of density; and from hence the difficulty of laying down any correct formula for these refractions, whilst the law of evaporation is so little understood, which indeed seems a task not easy to surmount. The effect indicated by the barometer and thermometer is insufficient: and should the hygrometer be improved to fix a standard for moisture in the atmosphere, and shew the variations near the surface of the ocean, which certainly must be taken into the account, (evaporation going on quicker in a dry than a moist atmosphere,) the theory might still be incomplete for correcting the tables of the dip. I shall therefore conclude this paper, by shewing a method I used in practice, in order to obviate this error, in low latitudes.

When I was desirous to attain more accurately the latitude of any head land, &c. in sight, I frequently observed the angular distances of the sun's nearest limb from the horizons, upon the meridian both north and south, beginning a few minutes before noon, and taking alternately the observations each way, from the poop, or some convenient part of the ship, where the sun and the horizon both north and south were not intercepted; and having found the greatest and least distances from the respective horizons, which was at the sun's passing the meridian, and corrected both for refraction, by subtracting from the least, and adding to the greatest altitude, the quantity given by the table; and also having corrected for the error of the instrument, and the sun's semidiameter; the sum of these two angular distances, reduced as above, — 180°, is equal to double the dip, as by the following

EXAMPLE.

The sun's declination 4° 32′ 30″ north, and its semidiameter 15′ 58″ took the following observation:

		South.		North.
The meridian distance of the sun's nearest limb from the horizon of the sea	-	78° 36′ 30″	=	101° 1′ 20″
Refraction *per* table	- -	— 0 11	=	+ 0 11
Distances corr. for refraction	=	78 36 19	=	101 1 31
Error of the sextant	- -	+ 1 32		+ 1 32
Sun's semidiameter	- -	+ 15 58		+ 15 58
		78 53 49		101 19 1
½ diff. or the dip found	- -	— 6 25		78 53 49
Altitude reduced	- =	78 47 24		180 12 50
Zenith distance	- - =	11 12 36		180
				Diff. 12 50
The sun's declination N.	=	4 32 30		½ = 6 25 Dip.
Latitude of the ship N.	=	15 45 06		

I regret that I cannot in this paper insert the dip which I have found in my observations; for I only retained the latitude of the ship determined thereby, as is usual at sea; I generally rejected the error of the instrument, the dip, and semidiameter, as they affect both observations with the same signs, and reduced the observation by the following method:

	South.	North.	
Sun's dist. as before	78° 36′ 30″	101° 1′ 20″	
Refraction - -	— 0 11	+ 0 11	
Dis. corr. for refraction	78 36 19	101 1 31	101° 1′ 31″
		+ 78 36 19	
Sum of S. diam. dip, and		Sum 179 37 50	
refraction = ½ diff.	+ 11 5	180	+ 11 5
	78 47 24	Diff. 22 10	
		½ 11 5	101 12 36
	90		90
The ½ dist. as before =	11 12 36	½ D. =	11 12 36

It may be observed, that neither the dip, semidiameter, or index error, can affect the zenith distance of the sun's centre; and the refraction being small near the zenith, the result must be true if the angles are accurately taken; and it is only necessary to observe, that when the sum of the distances is less than 180°, the half difference must be added to the distances, as by the last reduction. There is a difficulty in making this observation when the sun passes the meridian very near the zenith, as the change in azimuth from east to west is too quick to allow sufficient time; nor can it be obtained by the sextant when the sun passes the meridian more than 30 degrees from the zenith; for I never could adjust the back observation of the HADLEY'S quadrant with sufficient accuracy to be depended upon.

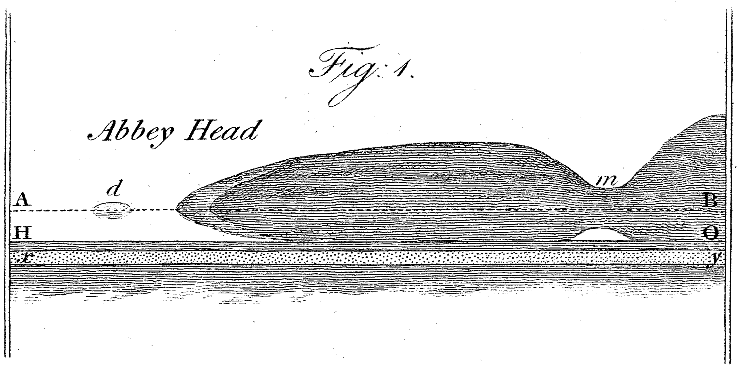


Fig: 1.

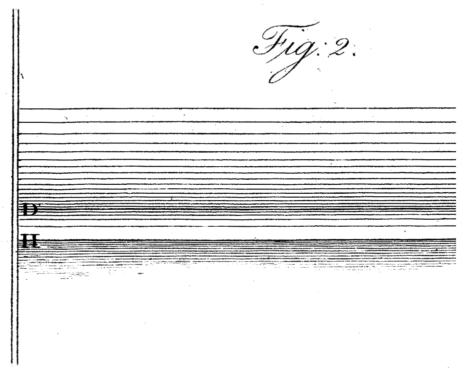


Fig: 2.

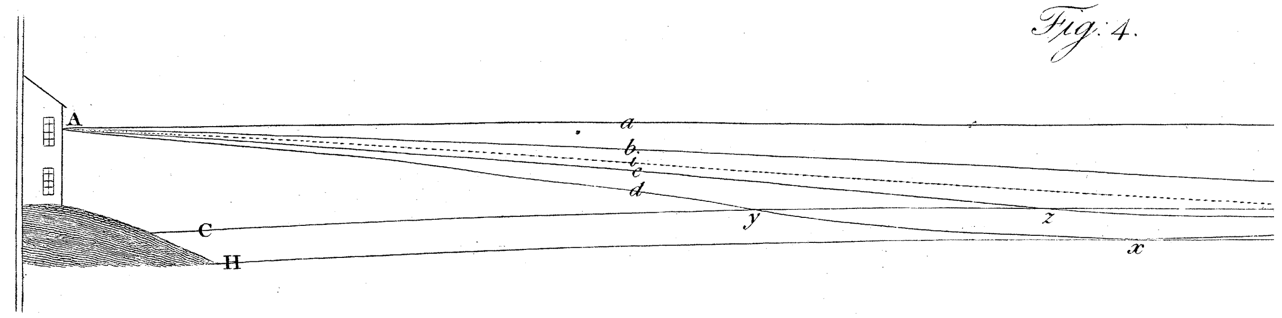


Fig: 4.

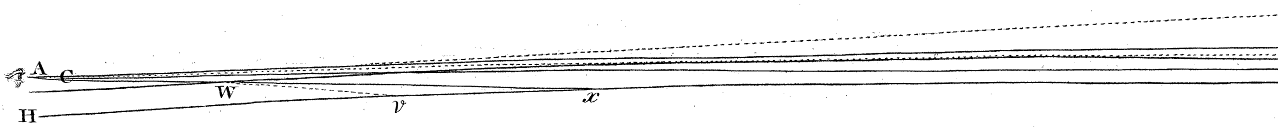


Fig: 5.

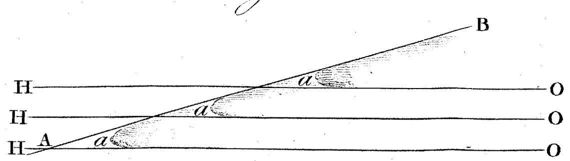
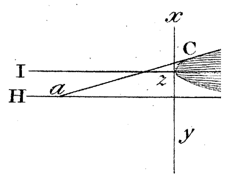


Fig: 6.



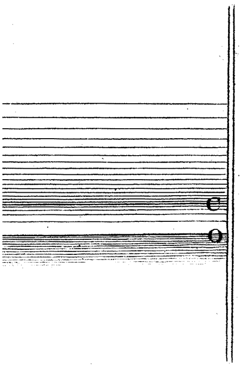
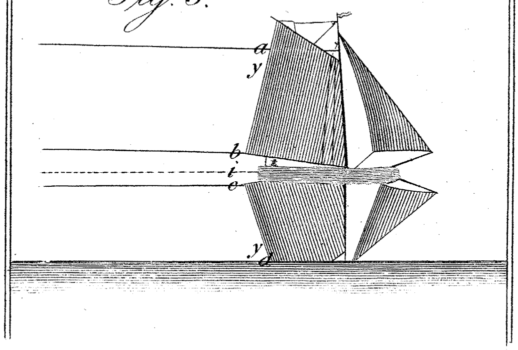
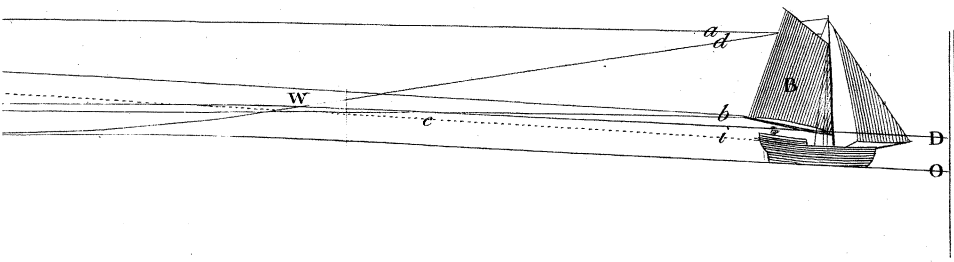


Fig: 3.





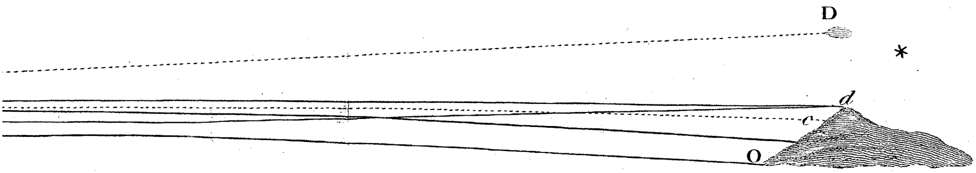
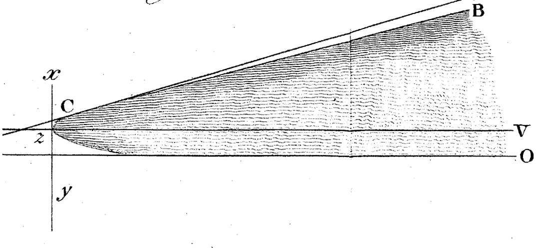


Fig: 7.



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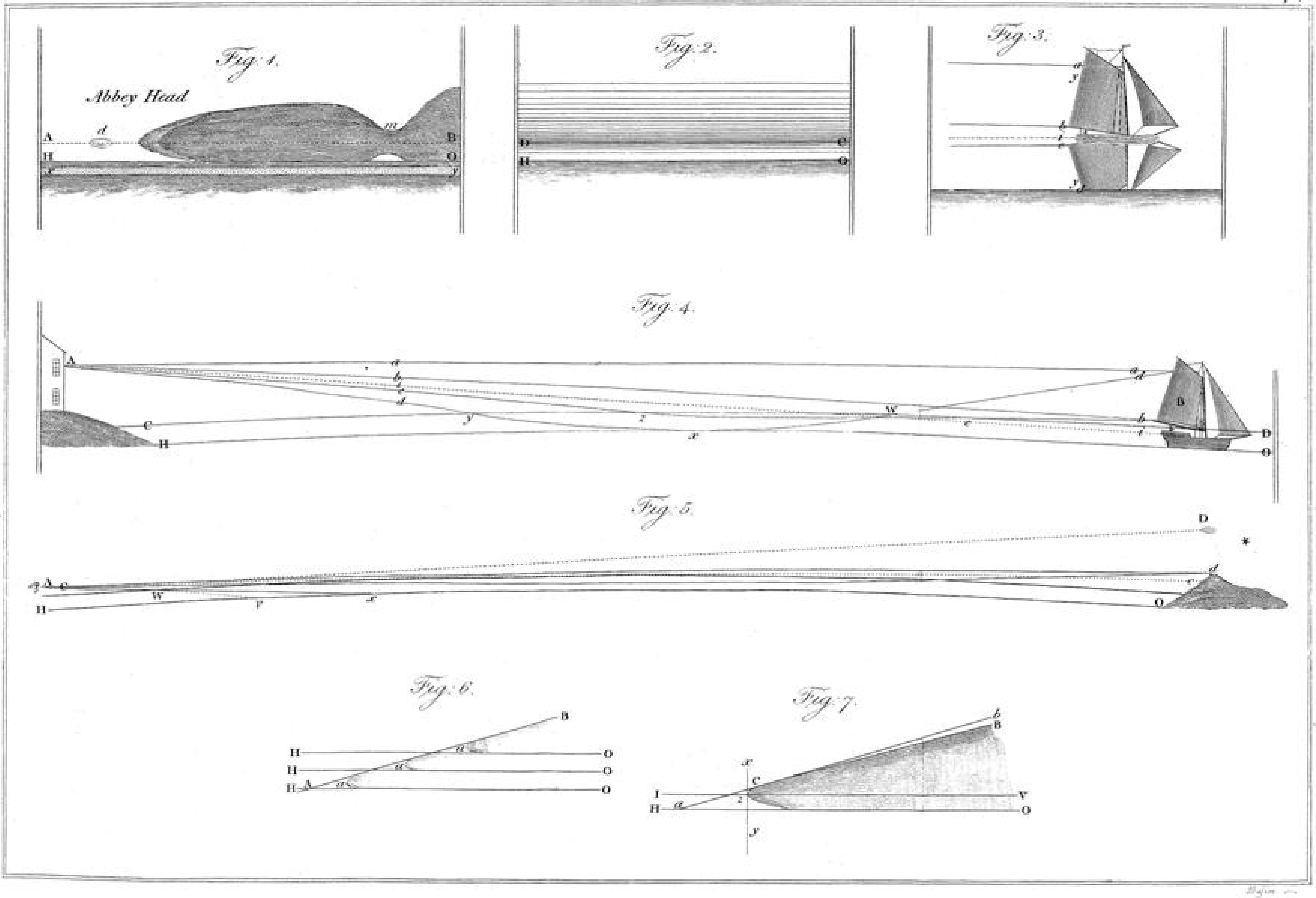
Fig. 1.
Abbey Head
Fig. 2.
Fig. 3.
Fig. 4.
Fig. 5.
Fig. 6.
Fig. 7.