JOHN SMEATON'S WINDMILL DESIGNS

J.S.P. Buckland

Background

The windmill work of John Smeaton (1724-92), between 1754 and the early 1780s, is inconsiderable compared with his watermill work. His pioneering use of breast wheels on sites where impulse (undershot) wheels were previosly used, seems to have led directly to the virtual supersession of the latter by the former in the 19th century. But his design concept for windmills established no trend in the 18th century development of the large modern corn windmill, and so his work is to a large extent atypical of contemporary and later practice.

However, his designs are of considerable interest. Smeaton grew up at a time when the normal English windmill was very largely the direct drive one pair toll mill. Most of them would have been post mills, with some equally small tower mills in such western counties as Devon, Cornwall and Somerset (1). It is possible that the smock mill was then only used in fen drainage (2). Edmund Lee's fantail and striking rod sail control patent of 1745 for a self- acting windmill shows the scale of a tower mill clearly enough: it is so small that his (admittedly cumbersome) fan has to be mounted on the end of the tailpole, just as it was to be on Sussex post mills in the 19th century.

The really large windmills were then only to be found in Holland. Their rapid development to their incredible size occurred in the course of the 17th century; and it is the second half of that century and the 18th century that is the time of their real European fame. A note on them, of January 1662/3, is amongst the earliest papers of the Royal Society. Headed "Wynd mills in Holland by Mr Bruce", it reads:

> Contrie drained, by screw mills of two sorts, one, Whose Cylinder turnes; the other, which hath a scr[e]w, yt goes round in the cylinder, which stayes fast.
>
> By scoop mills of two sorts; one, which must be turned to the wind by mens hands; the other, which is a great deal lesser, turneth it self to the wind by a great broad saile of boords, which it hath at the opposit end.
>
> They grind their cornes
> They full their cloath
> Make oile
> They saw plankes, saw Ebony, & other hard wo[o]ds for covering cabinetts &c. And saw Marble stones.
> They prepaire their earth for potters
> They beate hemp, & flax
> They make gun Powder(3)

Smeaton knew the designs of the Dutch windmill, after these had become, by 1685 (4), very static and extremely standardised, from his fascinating three weeks' tour in the Netherlands in 1755 (5); and from the Dutch millwrights' books which he had previously studied carefully.

Smeaton is therefore more prominent as a pioneer of the large windmill in this country than as an improver of existing practice. The scale of his smock mills was scarcely reached by other English windmills before the end of the 18th century, became common only in the 19th century, and for smock mills was not exceeded. To a large extent therefore, he was out on his own, and his designs should be seen in that light.

Wakefield mill; cast iron shafts.

Smeaton's first complete windmill design is his rape-seed oil-expressing smock mill at Wakefield, Yorkshire, of 1754-5 (6). He designed it for a Mr Roodhouse, and it was "executed" (i.e, built) in the latter year. Smeaton added a logwood chipping engine to it in 1756. The elevation and ground floor plan is reproduced in Rex Wailes's paper on Smeaton's windmills in Trans. Newcomen Soc, xxviii (1951-3), plate 32; and vertical section in Wailes's English Windmill (1954), plate 9.

This mill exemplifies what Smeaton achieved. The mill proper is a tall, massive, square base, which he calls the mill house. Its angles are chamfered off above the ground floor. The octagonal smock tower springs from the mill house roof internally to the walls. These have a uniform thickness of 2' (610 mm). It has no floors, and is a semi-open frame, covered with widely spaced horizontal slats, angled outwards to drive off the rain. Significantly, Smeaton calls the whole tower "the Lantern". The sides are cross-braced. Cross bracing has never become common in England, but is normal Dutch practice. In section the cant posts are square (including their outer faces), and not tapered inwards, as the economy in the use of long timbers imposed on English millwrights in the 19th century was still, in the mid 18th century, only a developing constraint on their use.

There is a shot curb with 18 rolls; an ogee cap with ball finial whose stalk is the upward projection into the ball of the cap ribs; endless chain winding; four cloth sails whose whips stop at the centre of the windshaft and are 9" x 4" (229 mm x 102" mm) at the centre,and 6" x 6" (152 mm x 152 mm) at the points, which are capped; an external weatherbeam of 12" x 12" (305 mm x 305 mm) section; an upright shaft sprattle across the under side of the sheers and a tail beam across the upper; and cap projections fore-and-aft to cover the neck of the windshaft and the winding gear. To prevent distortion of the curb, the cant posts at 2' 6" (762 mm) below it are braced by two horizontal squares, which break joint with each other and have a cant post at each angle; a peculiarly Smeaton idea.

The mill's overall height is 70' (21.3 m) to the underside of the ball of the finial, two feet (610 mm) less than the reported height of Cranbrook. The base is 28' high x 27' square externally (8.5 m x 8.2 m). A gallery is formed on its flat roof. The smock tower is 29' (8.8 m) high from its springing to the top face of the curb, 20' (6.1 m) wide at its springing and 15' 6" (4.7 m) below the curb, both externally measured.

For the stocks and cross-mounted sails, see below under the Leeds flint mill; their span is 61' (18.7 m). In 1759, Smeaton wrote that when the sails of the (Wakefield) mill did 11 r.p.m, the two edge runners did 7 r.p.m. (a sail speed to runner ratio of 1 : 0.64); "whereas 2 horses, applied to the same 2 runners, scarcely worked them at the rate of 3.5 turns in the same time". (7) His experimental data told him that the tip speed to windspeed ratio of his own sails, enlarged at the points, working loaded, was 2.6 : 1. Therefore, he said, the windspeed was 13'/sec (4 m/sec, or mid Beaufort 3). He calls this a fresh gale, but Beaufort 3 (3.4 - 5.4 m/sec) is a gentle breeze. But if we assume that the ratio was nearer 2 : 1 (8), the windspeed would be between Beaufort 3 and 4, the latter (5.5 - 7.9 m/sec) a moderate breeze that sways branches. However, these terms are distinctly subjective (Smeaton himself is imprecise, for in his windspeed tables 13'/sec comes between a gentle pleasant wind and a pleasant brisk gale); we are dealing with a fluid flow which is both erratic and very hard to assess with precision; and whose kinetic energy varies as the cube of its speed.

The sails of the Wakefield mill, unlike those of a corn mill, are geared down to their load. One would expect them therefore to turn fast in a good wind, like a drainage mill's, and so to have a reduced tip speed to windspeed ratio (unless their very wide points braked them too much). But Smeaton implies that they were loaded to a maximum, and that they conformed to the typical performance of a 60' (18.3 m) span (corn) mill's sails, which in a fresh gale and loaded to a maximum, turned at 13 r.p.m. Smeaton extrapolated from his model test data that each of his improved sails at 13 r.p.m, in this same "fresh gale", would develop the power of 18.3 men working at the rate of 145 watts each. This is 2.5 kw/sail, or 31.2 men working at 85 watts each; which gives 10.6 kw at the windshaft, or 14.3 h.p. So at 11 r.p.m. the windshaft power of the (Wakefield) mill would be 11/13 of this, or 8.9 kw (12 h.p.). But this is impossible, as at 13'/sec the theoretical maximum (59.3%) of the kinetic energy of the wind cylinder traversing the sails that may be converted into mechanical power on the windshaft is 6.2 kw or 8.3 h.p. (9). Nor can Smeaton's figure be reconciled with his comparison with two horses. If these delivered 1 kw to the edge runners at nearly 4 r.p.m, double the speed would need 2 kw, which with 50% transmission losses, would mean a windshaft power of 3 kw or 4.33 h.p. But if the windspeed were 5.5 m/sec, and the sails converted 0.2 (10) of the theoretical maximum of the energy, then the windshaft power will be 3.3 kw, or 4.4 h.p.

In 1782, Smeaton wrote that in 1755 specifically, he pioneered the use of big castings in millwork. He must mean by this, or include in this, the short cast iron windshaft on Wakefield, which, with its cross, is ca 10" 6' (ca 3.2 m) long. He claimed too that his success in 1755 had drawn cast iron into general use in the North of England (11). Doubtless this was true enough for a handful of large industrial plants. But the use by Smeaton himself of cast iron or waterwheel shafts dates only from 1769; in 1770 he designed a boring plant for Carron Co. with large cast iron spur gears with integral teeth; and his infrequent use of cast iron pinions or nuts does not predate 1778 (12).

The 1755 date is confirmed by another letter of Smeaton's, dated 26 May 1785. This was written after his "Coal Machines", or returning engine and waterwheel colliery winding gins, with gear reversal of the winding barrels, of which he was very proud, had suffered a small spate of shaft breakages. The letter reads:

> My dear Brother Walton
> I was much obliged and pleased by your Account of Warren mill: I intended as my masterpeice [sic] in the millway and hope I shall not be mortifyed by a failure of its Axis. This is a lease [??] very hard upon me; it is now full 30 years since I had the first Iron Axis Cast; and have made full and free use thereof, for 15 Years past, without the least appearance of failure in the maney in use; and now, no less than 5

> failures in one Year; and 2 [possibly read "4"] Axes totally Destroyed. I cannot promise myself that Warren Mill axis is more perfect as to the solidity of the Mettal, than the rest; but as I cannot but attribute all the failures to the Jarring of the Brake; that circumstance Cannot attend Warren mill. & in regard to the Wind Mills, as their brakes are not laid upon them, once for 200 times, that occurrs in the Coal Machines, I would hope they will not disgrace me either (13).

(His hopes for the Warren wheelshaft were soon to be dashed: after running for only some 18 months, in December 1786 it broke, and was replaced by a wooden one) (14).

Four days later, on 30 May 1785, he wrote further on the topic, to Thomas Barnes, the viewer at Walker colliery, Northumberland, where another of his winding engines had been erected in 1783 (15):

> It now appears to me that cast Iron, has a lesser degree of Elasticity than any other Substance in proportion to its hardness: which induces this property; that what ever exeeds its powers of Restitution at Each Shock of the Brake, tho in ever so small a quantity, will in time amount to a Sum, sufficient to disunite the parts, that is to break it, which it will always do in the weakest part

This is where the shafts have appeared honeycombed. Smeaton has therefore made the present shafts for Walker stronger in those places, so that

> I trust they will always continue to resist the repeated impulses, as by greater strength they will be Within the powers of perfect restitution.
>
> I have not the least doubt but that the particular stress in those Axes, arises from the Brake: because it is now 30 Years since I first introduced Iron Axes, into Mill work; and the first remains Whole and Sound to this Day; and almost without Wear; for 15 Years past I have used them in Millwork, in ordinary [i.e, as a routine], but in no case have they ever discovered any singns [sic] of failure, the Coal Machines where the brake is so very often laid upon them, only Excepted (16).

One can only wish that Smeaton had identified his first cast iron shaft or shafts, but it seems likely that the Wakefield windshaft must be meant. So this windshaft will therefore point a first; but it is of no great significance otherwise, as the general introduction of cast iron into English millwork is a 19th century development. Of greater interest is where it was cast. Carron Co, which Smeaton latterly used exclusively, only went into blast in 1760. But cast iron Newcomen engine cylinders had been a regular article of trade of the Coalbrookdale Co, Shropshire, from 1722. So did Roodhouse have to go to Shropshire to get the windshaft and cross cast?

The tower serves no function other than to carry the motor and the drive from it; exactly as did the windwheel towers of the latter 19th and early 20th centuries, strutted up above the farm buildings whose light machinery they drove (I have to thank David H. Jones for first pointing this out to me).

The tower had no floors, for these would be no more accessible than the loft of a house - and no house has a loft with the three floors that would fit into the tower! The way up a windwheel pylon is by a cat ladder fixed against it, with rungs spaced at 1' (305 mm) centres. This is far easier to climb than a mill ladder. The slats on the Wakefield mill tower would preclude an external ladder, and it cannot be against the inner face. So doubtless a single fixed 30' (9 m) ladder was set up inside the tower; or if its whippiness was thought to be too great, two ladders connected by a platform bracketed off the tower. Wimbledon Common mill, Surrey, though as rebuilt above the base in 1893 as a small smock mill masquerading as the one-off hollow post mill it once was is a post-working total oddity, has just such a ladder access. I recollect no difficulty in climbing from the ladder into the tiny cap (the top of what appears to be a small buck) (17).

Access to the Wakefield cap would be needed only for routine maintainance, such as greasing the neck journal, and for repairs. The sails are set and the mill is luffed from the stage. The brake rope hangs down inside the tower, somehow passes round a series of pullies spaced between the cant posts at the bottom, and then seems to go through the roof to the ground floor of the mill house. The weighted brake lever has a rope reduction pull-off, and apparently no swinging catch to hold it. Surely this is an old device?

Except for the iron windshaft and cross, the millwork details are normal for the time. There is a lantern wallower, and a down-turned face gear and a spur gear on the upright shaft, in the upper chamber of the mill house. The main plant is in the lower chamber. It comprises two sets of edge runners, driven off the great spur, and two stamps in adjacent bottom corners. These are worked off a camshaft, three-step geared from the down-turned face gear. The bins, &c, round the ground floor are titled (going anti-clockwise): "Meal for the press"; "Oyl Cestern"; "Seed crushed by the Rolls"; "Mealed the first Time"; "Mealed the second Time"; "Cakes once pressed"; "Meal for the press" (again); and "last pressed Cakes laid here" (18). Access to the upper chamber is by a staircase, not a ladder. This floor has a deep hopper with something rotating in its base [rolls for crushing the seed before grinding them under the edge runners- Ed.], also driven off the face gear, but apparently there is no hoist.

The whole plant and house is really a watermill, except that the drive comes through the roof. Or as Smeaton put it in 1786 (speaking of a watermill):

> The Millers busyness, properly speaking, is to keep every thing within the [mill] House in proper working order, and provided the MillStones are of right Speed & work with proper power, he does not need to trouble himself what is doing on the outside of the House, whether the Wheel is turned by Water, or by Quicksilver; if it Communicates proper action to the inside movements, that is all that need be sought for ... (19).

The royal soke of Wakefield (for corn milling, also fulling) was a monopoly appreciating in value as the size and prosperity of the town, based on the woollen trade, increased (20). The soke grantee in the 1750s was Sir Lionel Pilkington (1706/7 - 1778) of Stanley, near Wakefield, 5th Baronet and MP for Horsham, who had suceeded to the title in 1716. In 1754, Smeaton had designed a merchant mill for him at Wakefield, which was built (21). Sir Lionel had, most clearly, a great interest in defending his monopoly. One result of this was that Stephen Roodhouse had to write him a grovelling letter. It is addressed to the baronet at Westminster, is dated from Wakefield, 24 March 1755, and reads:

Honod Sr

Mr Barham shew'd me a Letter from you wherin you Expect I sho'ld give you Security that my Mill will not be converted into any other way than what's intend'd for that the Mills in your Soak may not Suffer, I don't know what people may say to you, it's not intend'd for any thing else [i.e, than oil-seed expressing] & when I do Attempt to do any thing of that Kind It will be soon enough then to prevent me, but if you have a Right to prevent me Building an Oil Mill, within the bounds of your Soak which is the intent of my design (off which Mr Smeaton can make you sensible) I'll then give you such Security as you shall think fit, but believe I have a right to build any Kind of a Mill Excepting to grind Corn for yr Soak & to Mill Cloth but when you come into Yorkshire if you think it proper Shall do all in my power to Satisfie you & I am Sr on all Occasions.

Your most Obedient Servant to Commd

Stephen Roodhouse (22)

A Stephen Roodhouse is one of the non-armigerous gentry listed at Wakefield in the Universal British directory, iv, London, 1798, p.657a. A Mr Roodhouse owned property in Wakefield in 1871 (23).

Smeaton may well have been influenced in his design by the Dutch industrial mills (the saw, paper and oil mills), where the smock tower rises above a long range of buildings; or even by the drainage mills, which are mostly empty space (24). However, the semi open-frame seems to have been his own idea, for the massively over-strong Dutch towers are clad with thatch. This is so weatherproof that certain of their drainage mills are credibly dated back to the latter, and even the mid 17th century. The English weather-boarded their towers, and never mastered the problem of weatherproofing the angles where the boards abutted. Driving a metal soaker under each abutting pair, though not a new building practice, for windmills is a 20th century technique; indeed it may only date from the time when the late Mr Thompson, millwright and engineer of Alford, Lincs, came south into smock mill country after 1945. Smeaton's open frame therefore had the double merit of keeping the tower ventilated and of preventing water from lodging. It therefore probably helped to extend the tower's life, but whether Smeaton realised this I do not know.

The article "windmill" in William Nicholson's British Encyclopedia, vi, London 1809, confirms this view of the Wakefield mill. The plate, published in 1808, is that the mill's vertical section, redrawn by John Farey jr. (1791-1851) into a corn mill. The cap has become a dome; and he has substituted for the oil-seed expressing plant a pair of 5' (1524 mm) and a pair of 4'6" (1372 mm) stones with wing nut tentering on the bray iron, on a hurst strutted off the ground floor. This part is probably derived from Smeaton's later Chimney Mill design. Farey seems to have put in no hoist. I have scaled it almost identically to the original. Farey is simply the draughtsman. One W. Boswell, Esq, wrote certain of the articles on practical mechanics, and various anonymous men professional in their fields wrote or corrected others; the account reads as authoritative and first hand.

The upright shaft is carried on a massive base plinth. The text says that the mill house is oblong in plan, shown cut across its long axis. The rest of it is used as a corn/flour store (perhaps the plant is at one end, as in a watermill with an external wheel). "The roof of the house is framed of large beams, a flooring is laid on these beams, and then the whole is covered with sheet lead". The eight cant posts (my term) "are framed into the roof of the house, and disposed round in a circle". They "are braced by cross pieces framed between them, so as to render the whole building very staunch; the outside is covered with weather-board, just to shoot off the rain, but open enough to admit the wind to pass freely through the house" (i.e, the tower). Shot curb of 36 rolls. Two truck wheels for centering towards the rear. Brake of five wood flexible segments joined together by iron hinges. Brake held off by hooking the brake rope to a hook on the cant post (i.e, there was a ring of eight hooks round the tower).

What is described here is the class of Dutch "factory windmill". An engraving of 1783 shows a smallish weather-boarded smock tower above a big, tall square base surrounded by a huddle of buildings, at West Ham, Essex (25). Clearly, this is the Abbey Mill, West Ham, shown with a very tall, apparently square base in a drawing of 1830 (26), and burnt down in 1862 (27). The Wandsworth brazil mill was a smock mill erected on a large square base. This was the same height as the watermill it was built against (28). An n.d. design of the engineer John Rennie (1761-1821) is a close, careful parody of a Dutch smock sawmill, e.g, the proportions of the smock, its slope, and the size of the cap in relation to it, are all just wrong. It has a few native features too: stock and whip constructed sails, imposed by the scarcity of very long timbers in this country; the brake lever directly coupled to the brake band; three finials along the ridge of the Dutch style cap, probably an English conceit; and a comparatively short wooden windshaft, perhaps based on Scottish threshing windmill practice. There is no evidence that the mill was built (29). A fantailed smock mill on Blackhorse field, Deptford, had a square base two floors high. The stage formed its roof, which the tall, slender smock flared out Dutch-fashion to meet. It latterly ground cork, and was burnt down in 1854 (30). And there is a drawing of 1823 by William Cubitt, showing his patent sail on a smock mill. The smock is circular, clad with metal plates, and is set on a big, square, two-floored base. This has an offset range of buildings either side of it (31). These rare exceptions apart, though, I doubt such factory mills existed in this country. But the value of the description in Nicholson is not lessened on this account, as it is written round a re-drawn mill by someone who understood perfectly Smeaton's design concept, though he is not named.

Other Early Work.

Ignoring his n.d. gear ratios for J. Pease's windmill at Sculcoates, near Hull, which may be part of his returning engine worked oil mill design for Mr Pease at Hull of 1754 or 55 (32) (fortunately for his tyro career, not built, as his first Newcomen engine of 1766-8 was a near disaster), Smeaton's other early windmill work probably pre-dates Wakefield. The title as printed of his own mill list of ca 1779-80 is "List of mills executed"; but the list impartially comprises alterations and new mills. It has two chronological sequences, and only a rough date order inside them. But the first entries are doubtless in precise order, and are: Nine Elms china windmill (n.d.); Barking wood windmill (n.d.); Halton watermill (his first mill to be built, in 1753); Wakefield watermill (for Sir Lionel Pilkington Bt, built 1754); Wakefield oil and wood windmill (built 1755) (33).

For the Nine Elms (Vauxhall) china mill he designed tubs and tub driving machinery, which was executed. He designed for it what must be the first set of his early splayed design of mill sail after his model experiments of ca 1751-2. And they were doubtless put up, as in 1759 Smeaton referred to the use of these sails not only on new mills (sic to plural), "but where they have been substituted in the place of the" ordinary sails; however, even the thorough work of Michael Short has failed to throw much light on the Nine Elms mill. (34)

To the log-wood mill at Barking, Essex, Smeaton made unknown changes. This (before the changes) had a peak stone runner 4'6" (1370 mm) in diameter, 1' (305 mm) thick at the eye and 6" (152 mm) at the rim, a 30-knife circular rasp and an 8-knife cutting engine. Its sails may serve as a datum against which Smeaton's may be judged. "Midlings" (stocks) 9" (229 mm) face x 12" (305 mm) deep (i.e, at the poll). Whips (so named) 30' (9.1 m) long, so span 60'+ (18.3 m+). Sail frames 27'6" (8.4 m) long xx 6'2" (1.88 m) wide (the driven whip), lead board 18" (457 mm) wide, an overall point width of say 8'2" (2.49 m). Sails "Weathered $2\frac{1}{2}$ inches in $8\frac{1}{2}$ " (31).

Leeds flint mill.

After Wakefield, Smeaton had no further windmill work till 1774. In that year he designed for a Leeds flint (pottery) mill an iron windshaft with a flanged box to mount the clasp arm brake wheel on, and a five-armed cross, both cast integral with the shaft; five cloth sails; a cap frame and a shot curb. The windshaft, cross and sails are illustrated and described in Rex Wailes's paper in Trans. Newcomen Soc, xxviii, who notes that they appear "to be the first record of a five-sailed mill in England, and possibly in the world". Smeaton used five sails thereafter. The Newcastle magazine in 1827 said that his use of them was a great improvement, "not so much the gaining of a fifth power, as is supposed, as the equalisation of motion in squally winds" (vi, pp 280-3).

On the Leeds flint mill, it is also of interest that Smeaton has transformed the sails from his early design of splayed ones. These were derived from his model experiments of the early 1750s. One of them, for a 70' (21.3 m) sail span, has a huge 13'9" (4.19 m) overall point width (36).Another, on Wakefield, has a 61' (18.6 m) sail span; and while each sail's trailing frame widens only gently from ca 6' (1.8 m) to ca 6'10" (2.08 m) at the point, the leading frame increases from nil width at the heel to give an overall point width of nearly 12' (3.7 m) (37). These sails are much modified versions of the obsolescent double-sided cloth sail; and though they lack leading boards, must have caused trouble.

In total contrast, the frames of the Leeds sails are a nearly complete reversion to standard practice. The sail span is 70' (21.3 m), and the trailing frame is 5'4" (1.63 m) broad, but the overall point width with leading board is only 6'6" (1.98 m) (38). The board dies into the back at the heel, a near vestigial concession to his early practice.

Wailes notes that each Leeds sail back has a back-stay butting against the end of the cross. Smeaton never finalised his sail mounting. On Vauxhall he used a single full length stock through a wood poll, in the Dutch fashion; how the timber was to be found I do not know. On Wakefield and thereafter he used a cross, but one whose arms were always too short to risk carrying backs on them unaided. So on Wakefield the whips are mounted on stocks crossing in same plane (presumably housed together), and have a very short bowsprit. On Leeds, the back braces replace both stocks and bowsprit. The braces are best regarded as wooden extensions of the cross, increasing its radius from ca 3'2" (965 mm) to 10'4"(3.15 mm) (39). And on Chimney Mill, backs are used alone, but with a very long bowsprit for tensioning (see below).

Smeaton's directions for weathering the sails on the Leeds flint mill are dated from Austhorpe, 29 April 1774 (40). So work was doubtless just completed before disaster struck, it is tempting to suppose, the same mill. For in 1774:

> On Sunday, July 31st, the sails of the windmill belonging to the Leeds pottery fell down with a tremendous crash, which, being looked upon as a judgement for desecrating the Sabbath, the proprietors resolved that the mill should never be allowed to be worked afterwards on the Lord's day (41).

Sykefield mill, Leeds.

A few years later, Smeaton designed two windmills from scratch. Of these two, the Royal Society holds no drawings of his oil mill for his son-in-law John Brooke, built on Smeaton's own Sykefield estate near Leeds. Smeaton delighted in his new toy: on 20 January 1782 he wrote from his home, Austhorpe near Leeds, to the client for his next windmill:

> My mill continues to perform in a very Extraordinary Mann[er] ... has not been the average of a day in a fortnight, without ... some work done ... I hope yours will give satisfaction, but will never be her perfect equal (42)

And on 7 February 1782, Smeaton wrote Carron Company:

> The windmill axis, and oil press, that you cast for me the year before last, the former has withstood the fury of all the storms that have happened since, without the least likelihood of injury, and yet one blow of the Deptford piling-ram, properly direccted, would destroy it. The oil-press is in constant work, and every five or six minutes is subject to an alternate pressure and release from it equivalent to 300 tons of dead weight, tending directly to rend it in two; and yet, I believe, a single well-directed blow of a sledge-hammer, would break it. (43)

The mill was not fully completed, though, till about April 1782 (44). The millwright who erected it was Mr Jonathan Crowther in Kirkgate, Leeds, "a very intelligent able Workman, ... accustomed to take his Work by the Great" (i.e, to contract for the whole job) (45). On 7 November 1782, Smeaton wrote from Austhorpe to his close friend John Holmes, a London watchmaker,

> that having had a couple of Days hard frost, Mr. Brooke is in great fear of his Oyl; having suffered a good deal thereby last winter; as well as much trouble. a council being called this Morning, I have advised to get Some thing in the nature of a Dutch Stove.

Smeaton therefore asked Holmes to buy such a stove in cast iron in London, for

Brooke's stone-floored "Oyl House"; and to

> Send it by the first Carryer to Leeds; directed to be left for Mr Brooke Sykefield Mill Austhorpe. If there happens to be Elbow pipes &c, to convey the Smoak out of a Window it is well; otherwise they can be made here to fitt the place (42).

Smeaton's first assistant was William Jessop (1745-1814), who rose to be a distinguished engineer in his own right (43). Smeaton's second, and last, assistant was his first cousin Henry Eastburn. It has always seemed to me that he was a complete nonentity. He wrote Smeaton from his Whitkirk home, on 24 July 1784, that the strap and bolt anchoring to the cross of one back of (Sykefield) mill had failed; and that the back had then pulled free of the inward flanged cap clamping the backs together at the centre (44). In September 1786 a correspondent wrote Sir Joseph Banks, PRS, that "The high winds lately carried off 2 sails of Mr Smeaton's 5-sail windmill near Leeds" (44).

In March 1788, Smeaton wrote his friend Alexander Aubert, FRS:

> My son [in law] Brooke says your last advices concerning foreign Oyl, was very exact, he hears that a quantity of Oyl is or will be imported from Spain so as to bring down the price of Olive Oyl for manufactures: will you therefore be so obliging as to get a word of Intelligence in this Matter, for whatever brings down the price of Gallipoly &C Oyls, in proportion affects the price of Rape Oyl, which is the leading article of his Manufacture (46).

In December 1789, Brooke was enquiring about the rape-oil price in London (47). And Smeaton, in a codicil, dated Austhorpe, 20 September 1792, to his will, instructed his executors to repay Brooke between £400 - £500 "for the additional expenses of the Additional Works made to the Mill at Sykefield" (48).

Chimney Mill, Newcastle-upon-Tyne.

Sykefield was doubtless similar to the second mill, Chimney Mill, Newcastle-upon-Tyne (Designs, i, ff.10v-15). This mill is well-known because some of its plans were published in Smeaton's Reports (1812); whence the vertical section as reproduced in Alec W. Skempton (ed.), John Smeaton, FRS, London: Thomas Telford Ltd, 1981, p 80. The plans are dated 1781 and 1782. It was a flour mill. In the letter of January 1782, just quoted, he told his client, Mr Smith, that he had finished the general section of the mill, and everything else needed to complete her, the bolting mills only excepted. "When you come to see the quantity of Drawings", Smith will see he has not been idle, and he will post them for Newcastle the next day (53). His explanation for mounting the five backs is dated Austhorpe, 21 January 1782 (54). And on 28 January he wrote Carron Co:

> Gentlemen
>
> I find that according to [my] recommendation Mr Willm Smith Tobacco mercht at Newcastle who is erecting a Windmill under my direction, has applyed to You to cast him the main Axis, from the same model as mine was cast from [i.e, for Sykefield]; ... and as I am desired by Mr. Smith to give you such directions concerning it, as I shall approve; those are to keep Strictly by the former model; except

that if it Happens to ... [? be still neither] Cast nor molded, then that you will set the wheel flanch or Square box, only such [?? read one inch] further from the Horns, than was cast for my axle: if it is molded but not cast, the alteration is not of so much consequence as to Make the Alteration ... (55)

Chimney Mill uses the identical design concept to Wakefield, but is a bit bigger: base 33' (10.1 m) broad x 27' (8.2 m) high overall, its walls 2'3" (686 mm) thick; smock tower 31' (9.4 m) high, and 14' (4.27 m) internal diameter at the curb; mill 71' (21.6 m) high to the underside of the ball finial; and five sails of 69'6" (21.2 m) span. The backs were tenoned and housed together at the cross in a manner very carefully described and illustrated; as they could be drawn out singly, as well as being stirruped down upon the horns (the cross's arms) they were held by a circular iron disc with two down-turned flanges, bolted through the backs to the horns. This is typical of Smeaton's attention to detail; but when cross mounting became standard Lincolnshire practice in the 19th century, was ignored (56).

A massive (wood) bowsprit projects forwards 6' (1.83 m) from the iron disc, and carries four guy ropes, each tensioned by a pulley block to a point on the sail almost two-thirds its length, 23' (7 m) from the centre. The backs are dished gently forward. Each sail is 6' (1.83 m) wide, a width apparently uniform throughout, and including the lead board. The brake wheel is 10'4" (3.15 m) in diameter. The brake band is wooden, and acts on a cross section of 8" (203 mm).

Chimney Mill has two pairs of 4' (1.22 m) Cullen stones, and two pairs of 5' (1.52 m) stones (doubtless French burrs), all on the central 4'9" (1.48 m) high ground floor hurst, and with wing nut tentering. As there is no meal floor, this layout is cramped, but the height of the hurst allows a sack to be hung below each meal chute. Smeaton was doing no more than copying contemporary watermill practice.

There is a lantern wallower of 5" (127 mm) pitch, and peg-geared great spur and stone nuts of 4" (102 mm) pitch (in surviving practice a 4" pitch is coarse and uncommon). A wood upright shaft goes right down to the ground. It is in two parts, with a locating bearing at its join in the mill house roof (probably the Wakefield shaft is similar, but this is not clear). The shaft has an upturned face gear in the upper (bin floor) chamber of the mill house, which must have driven dressing machines and a hoist.

The mill has a floorless smock tower, whose cant posts spring immediately internal to the mill house walls. This far from Smeaton's Reports. As described from its present state, the plan of the brick-built mill house is square, and its roof timbers comprise two pairs of spanning beams, intersecting each other at right angles. They therefore make a noughts-and-crosses grid, the slot for the quondam upright shaft being dead central in the larger middle square of it. The ends of the beams rest on corbels on the inner faces of the walls. The cant posts spring from the corbels too (or rather, from the beams resting on them), and are now, it seems, fitted with cast iron shoes. "A very neat and nicely engineered solution," Mr Falconer writes, to the problem of carrying the tower without the risk of the cant posts splaying out (57); indeed, a much nicer job than in normal mill construction (58).

We return to the Reports. The mill house forms a very shallow cone sloping down from the apex where the upright shaft goes through it, so that rain water runs away from the shaft hole. Sitting just above the cone's apex is a collar fitted closely round the shaft, and turning with it. Immediately over this, a neck or sleeve is wrapped tightly round the shaft, turns with it, and falls outwards over the collar and down to the roof covering (59). Clearly trickling rain water had been a problem at Wakefield, which has a flat roof and neither collar nor sleeve.

While Smeaton has an elevation of the massive south front of the mill house alone, there is no other view of the smock tower; but it is clear that it was to be an open frame, as at Wakefield. And a broadsheet issued by the mill's owners in 1978, based on local research, says: "For 75 years the windmill smock had an open structure and was known locally as the Skeleton Mill. On Christmas Eve 1857 it was struck by lightning and caught fire: during the repairs the mill body was enclosed".

Continuing with the Reports, the mill has a six or eight sided cast iron windshaft, 11'4" (3.45 m) long; and a five armed cross (certainly cast with it), each arm 3'10.5" (1.18 m) long, a circle of 7'9" (2.36 m). The dome cap turns on a shot curb, whose rollers run between the smock curb and the cap curb. The four truck wheels for centering, two at the rear of the cap (where the back thrust is taken up) and two towards the front, are fixed to the cap curb; studs radiate from it to carry the domed, finialed roof, and the cap frame is mounted on it. The frame has a curved, partly external weather beam laid across the short sheers, and one main sprattle aft of centre for both the windshaft's tail bearing and the upright shaft's top bearing (sprung forward on a bracket). The long, converging fan sheers spring from the same sprattle.

The Chimney Mill fantail is the sole one in Smeaton's designs. It is the very first illustration of one known to me after Lee's patent drawing of March 1745/6; though by the date the mill was built, the fantail was in common use on the windmills around Leeds (60). The handrail of this fantail is dead horizontal. The two sheers, 20'4" (6.2 m) overall, extend 15' (4.57 m) behind the rearmost point of the dome, and have a tiny rise. The 10' (3.05 m) fan wheel has five narrow blades tapering into the hub box. It is mounted off-centre on its spindle, so "that the main sails may be canted a little from the wind's eye, the right way", a Smeaton subtlety. It is three-step geared down to the cast iron 16-segment spur rack, and rotates 3308 times to turn the cap through 360 (61). No worm is used. The cast iron gearing is, however, pre-cycloidial, and may be called enlarged clockwork, or reduced millwork. For example, the gear meshing with the rack is a lantern pinion.

The two white lead tower mills at Islington, built for the Rotherham ironasters, Samuel Walker & Co, in 1786 and ca 1792 (62), have five-bladed fantails almost identical to Chimney Mill's, thrust a long way out, and with only a slight rise. They are bow-spritted mills too, the first was initially a five- sailer, and are imported examples of the most advanced Yorkshire mill-wrighting (62). One of them, with four sails, is a middle distance feature in the plate titled "Baumes, formerly the seat of Sir George Whitmore", published 1 March 1795, in Daniel Lysons, The environs of London, ii, London, 1795, opp. p.488. In 1803 the Swedish metallurgist Eric Thomas Svedenstierna noted that around Hull "were various well-built windmills, which were all so equipped that they oriented themselves acording to the wind" (64). A spurious survivor of the early design of fantail is that on the 1890s rebuild of Wimbledon Common mill. This is a working fantail, with a 6' (1.83 m) fly, copied off that on the original mill built in 1817 as a one-off hollow post mill (65).

The fantail on the cap developed in two ways to the position close in and high up where it belongs. Either the fan sheers became shorter and steeper (as in Kent); or the cap sheers were extended back a short way and the fantail was sprung from them vertically, or nearly so (as in Cambs, Lincs). Excellent isometric views of most types except the Kentish one are published in Kenneth G. Farries, Essex Windmills ..., ii, London: Charles Skilton, 1982, p.93. The early design is big, clumsy, expensive and unnecessary, and can only have developed from a false, and doubtless unthinking analogy of the fantail with the tailvane. It has the disadvantage that in a strong wind it will indeed try to weathercock the cap round and so strip the fly tackle. Smeaton was a highly numerate man of science as well as a practical man, but in copying what he saw around him, even he for once nodded.

On 15 January 1783 he wrote Smith:

> Having brought a bad cold home with me from Newcastle, the first business I did after my return was to calculate a fresh the Number that would best Suit the West Side of Your Tobacco Mill ... I shall make no fresh Charge on this Acct. but as this is a time of Year when Tradesmen call for their bills on Engineers and Philosophers, as well as other men; will it be agreable to You to Settle my Acct. I value the Designs for Each Mill [either Smith's snuff mill and windmill; or his windmill and tobacco mill] with the attendance and charges thereon Annexed, at 30 Gineas. I received a Draft Value £30 this time twelve month so that a Draft for £33 more; will settle the Account in full ... (66)

However, in July 1783, William Smith of Newcastle-upon-Tyne, dealer, was declared bankrupt (67). Chimney Windmill was to be auctioned on 25 September 1783. The advertisement said that it was adapted for making flour for the London or other markets; that it had a No. 60 flour machine, and worked 60 quarters (17 m3) or more per week, had five sails, and an iron windshaft; was self-winding; [the cap] was covered with copper; and was designed by that celebrated artist, Mr Smeaton. Also for auction was its mill field and its granaries. An accompanying plan shows these as a long range of buildings attached to the mill (68). Shortly after this, on 1 November 1783, it was advertised to be let or sold (69).

A distinguished visitor to the mill was the great engineer John Rennie (1761-1821). He was very unimpressed by it. Under the heading "Newcastle upon Tyne", he noted down (date unknown):

> I examined three windmills about this place two of which were much the same as those I have formerly seen the other was done by Mr. Smeaton & had a Cast Iron Axis & 5 Vanes [sails] as normal with him there was a wooden house [smock] the height of the yards [sails] & then below that a rectangular house the top of which was wholly covered with Lead & below there was three pair Stones a Dressing Machin & common bolt Mill & also a Wheat Scrian but all of these was so badly placed as to render the working of the Mill exceedingly unconvenient. The top of the house turned of itself to the wind & the roof [the cap] was covered with Copper but notwithstanding all this finery She was a bad machine & in general so extravagantly constructed as to throw I had almost said a Stain on the Engineers Caracter as I'm told She cost £2500 (70)

To the younger contemporaries of John Smeaton his millwork must have looked ever more old-fashioned, and most of all to John Rennie, whose plant of 1784-6 for the Albion Steam Corn Mills, Blackfriars, was a world apart from it. Rennie's plant had cast iron spur and bevel gearing. Each of the two 50 hp double acting Boulton & Watt beam engines drove ten pairs of stones ranged round two great spurs. In 1813, James Watt wrote of it, "I believe the work executed here may be said to form the commencement of that system of mill-work which has proved so useful to this country" (71). From a longer perspective, it presaged the millwrighting of the greater part of the 19th century, whereas Smeaton's work, except in its scale, retained many echoes of a passing era.

Rennie was just as unimpressed by Smeaton's very large Carshalton watermill, Surrey, of 1780 (72). But a fresh eye and professional derogation apart (Watt observed in 1786 that "he has too much forwardness and conceit") (73), Rennie's criticisms of the banishing of the plant to the base of Chimney Mill are valid enough to explain why Smeaton set no trend in windmill design: if the tower is treated merely as a large pylon, there is a great deal of wasted space inside it, which is not true of towers for windwheels. And then the base has to be very big to make up for this lost space.

A favourable comment appeared in the Newcastle magazine for 1827 (vi, pp280-83). This said that the mill "continues to this day a model for correctness and completeness in the wheel work and their numbers, which shows that he [Smeaton] was master of every task he took in hand". There is no overlap here with what Rennie criticised, and as Smeaton paid strict attention to his gear ratios, the observation is probably true. The brakewheel to wallower ratio is 72:31, or 1:2.324. The great spur to stone nuts ratios are 72:26, or 1:2.769 for the 4' stones; and 72:28, or 1:2.571 for the 5' ones. The sails to stones ratios are therefore 1:6.432 and 1:5.972. Assuming the sails' working range was 8 to 20 rpm, the 4' stones would turn at 51 to 129 rpm, and the 5' ones at 48 to 119 rpm (which rounded, are 50 to 130, and nearly 50 to 120).

After the tower was clad, following the 1857 fire, the mill continued working, on the same site, till 1891 (74). Photographs show that though the fantail was rebuilt with somewhat raised sheers, it remained a stuck-out one, and the fan-wheel of six wider blades as still mounted off-centre the same side, giving an imperceptibly increased leading side weather angle to the sails. These were five double shuttered sails without leading boards or bowsprit, and followed the normal practice of rotating anti-clockwise viewed from the front. In its latter working days, the weather-boarding at the angles was covered with tarpaulins, very clearly indicating that the wet had got in.

In 1892, the Newcastle City Golf Club bought the mill for a club house. They put in large windows round the smock's lower part, a not inelegant alteration to it, and above them a ceiling nearly half-way up the empty tower. Presumably it was they who asbestos tiled the weatherboarding. The sails, less shutters, survived till they were sawn off in 1924; the fantail survived till 1933. In 1951, the cap was cut down to the frame, and given a weatherproof lid. At the same time, the then windshaft and cross were broken up for scrap. They fetched £10; in April 1984 their estimated replacement cost was £5786. The fantail rack (round the curb) is still in position, and the cap frame partly survives (75).

In 1975, the Stephenson Falconer Partnership (now Falconer Associates, Architects) bought the mill. It is their office, and without grant aid, they are slowly restoring it. They have spliced new sections into two quite badly rotted cant posts; stripped the tarred weatherboarding and tiling off; renewed the lead flashings on all eight sides, including those on the cant posts, with new lead, and for economy and durability have re-clad the tower with "Celuka" foam plastic weatherboarding on building paper (76). Mr Thomas Falconer writes me (letter dated Chimney Mill, 3 July 1984):

> ... the single floor in the smock was part of the Golf Club conversion, indeed it is not a floor at all just a ceiling. We intend to reinforce it so that ultimately it becomes the highest floor to which visitors can reach to see the inside of the cap. A floor has also been inserted across the base of the cap again for the Golf Club conversion, this we will remove. I am certain that the plant remained in the Mill House. The floor of the mill is concrete and shows signs, now covered by glued-down carpet, of the Hurst frame bases. It looks as though the concrete floor was laid before the hurst frame was fully removed and then removed after the removal of the stanchions.

John Farey jr. (1791-1851) drew it from Smeaton's original designs for the Reports (1812). He also redrew it, as two freelance designs, for both the Pantalogia encyclopaedia (1813) and for Abraham Rees's Cyclopaedia (1819). He kept the stones in the base, but put floors and ladders into the tower in both of them. In the Pantalogia version he has put a crash hoist and sacks of grain into the tower too, but in the Rees version he has put a crash hoist only into the upper chamber of the mill house. Both of Farey's versions are otherwise considerably altered from the original. It is quite clear that he made these changes because he did not understand the original design of the mill. And although he wrote the article "Windmill" in Rees, 19th century engineers did not concern theselves with windmills; even Fairbairn, in his Mills and Mill-work, simply rehashed the Chimney Mill elevation, and has nothing to say. Variants, versions and derivatives of Chimney Mill are the norm in English technical writing throughout the 19th century, and are worthless. That in William J M Rankine's prestigious Manual of the steam engine and other prime movers, 13th edition (1891), p.220, is nearly the last of them.

Stepney mill, Newcastle-upon-Tyne.

Chimney Mill cannot have been thought too badly of at the time, for in 1783 Smeaton redesigned the plant and sails for the very fat and steeply battered Stepney oil tower mill, Newcastle-upon-Tyne (not London), of Messers Landell & Chambers. This has 15' (4.57 m) internal diameter at the curb, and had a first floor stage. An inclined secondary drive is taken off a trundle-cogged face gear by a modified spur gear: the peripheral face of its radial cogs is cut on the slant so as to mesh horizontally into the face gear. The windshaft casting has a five armed cross and a box to take the clasp arm brake wheel (77). This looks like a transitional stage between a clasp arm wheel on a wooden windshaft and a wheel with an iron spider on an iron windshaft, but it became a standard way (with a keyed-on box) of mounting a brake wheel on an iron windshaft in Kent in the 19th century.

On 31 May 1783, Smeaton wrote Landell and Chambers that as the brake wheel was in a bad state it should be replaced by a bigger one "that the Brake may have a better command upon it", to be clasp arm, the central square 2'4"

(711 mm), 10" (254 mm) deep. The millwright, one J Walker, may fix the stones. And he concludes:

> As I perceive your mill Cap has no Rollers, but slide[s] upon a Circle of Iron; pray acquaint me if it has any additional Support upon the uppermost floor: other wise I am afraid the Additional Weight of the Iron Axis, and 5th. Sail will make the Cap to Turn very stiffly into the Wind. (78)

On 9 June, Smeaton wrote that the design for the alterations was settled and in hand; "The Design for the Iron Axis will be forwarded in a Post of two". The existing sails to stones ratio was about right, though on the slow side. But "I find both the Stamper Shaft and fire Works so egregiously wrong, that I wonder how ever they have made use of them". He assumes there are to be iron stampers, and gives the gear numbers for the stamper shaft and the fire spindle: "and then you will find those Works go pleasantly at all degrees of Wind" (79). On 12 June, Smeaton proposed "sending this Day by the Newcastle Machine, the Design for the Axis for Stepney Mill, with the Manner of fixing the Sails thereto -". He himself was to be in Newcastle the next week (80). The detailed instructions for first putting the five sails together on the ground (to test the complex tenon and mortice assembly at the cross), and then mounting them (i.e, one by one) are nearly identical to those for Chimney Mill (81). Stepney mill was Smeaton's last windmill. By 1827 it had become a corn mill (82).

Conclusion.

As an example of how the two-step geared tower windmill was actually developing, the design by the Shrewsbury millwright, William Hazledine, in Telford's MS "Treatise on mills" of 1796, points the comparison with Smeaton's windmill work perfectly. Hazledine was a forward-looking man, whose ironworks took up the manufacture of Trevithick's high-pressure steam engine in the next decade. His tower mill is a straight, enlarged development away from, and out of, the one-step one-pair stage. It is quintessentially English millwrighting, but the design vision of Smeaton is totally lacking (83).

Acknowledgements.

I wish to thank the Royal Society for granting me access to their bound volumes of Smeaton's engineering designs; and to the Institution of Civil Engineers for granting me access to their four MS volumes of Smeaton's press-copy out-letter books (his "machine letters"). I also wish to thank the latter body for permission to quote from them here.

(This paper as printed has been heavily revised since its presentation - Ed.)

Discussion.

PLUNKETT Did he only design smock mills, or did you not mention other types?

BUCKLAND He only designed smock mills - a total of 3 - and he may have been responsible for introducing the smock mill to this country, as opposed to its use as a drainage mill.

A BRYAN When he designed a mill, was he acting as the main contractor, or was he advising the millwright?

BUCKLAND He produced the design, which he then sold to the owner of the property, who would then get his own millwright to follow them. Smeaton had his preferred millwrights, but he was in no sense a contractor.

A BRYAN I heard he was connected with the pottery mill at Thorp Arch, between Thorp Arch and Wetherby. There is a mill there which ground for a pottery in Leeds. I believe there was a windmill associated with it which stood behind the surviving watermill, used for some undefined process. Have you any information?

BUCKLAND No. All I know of any pottery windmill is a proposal made in the 1780s, in which he stated what sort of windmill would be needed to drive it, but as far as I know, it didn't get any farther.

TURNER The mill at Thorp Arch ceased to be used and was replaced by one in Hunslet, a suburb of Leeds at that time. This was also a pottery mill, of this fairly early date.

BUCKLAND Which is the one attributed to Smeaton?

A BRYAN The one near Weatherby. It is mentioned in Rex Wailes, Mills for grinding stone. On that watermill site there is mention that there had been a windmill; it could have been a corn mill, but the watermill was used primarily for grinding for a pottery.

BUCKLAND Could it have been owned by the Wedgewoods?

A BRYAN I am not sure; I will look into it.

BUCKLAND I know of this one letter, answering this query from Wedgewood, but I don't know if anything came of it. If it did, there is nothing in Smeaton's designs in the Royal Society.

JARVIS I was puzzled by the fantail description. I can well understand that the fantail wasn't in an ideal position, but you said it failed mechanically in that bad position?

BUCKLAND It is a vulnerable position, because when you have a long horizontal fan stage to hold the fan out some 2 - 2.5 m, if it is struck by a strong side wind, the danger is that the fan is going to present a solid enough surface for it to act like a weathervane and try to push the whole thing round. When that happens, you are in trouble.

JARVIS I see, I didn't appreciate that point.

JONES You emphasised that before Smeaton, English tower mills were very small affairs, and that he had great influence on their scale.

BUCKLAND This is one of the most interesting facets of his mills. I believe he pioneered the large windmill - what is now considered the standard 19th century windmill - in this country. Before Smeaton there would have been small one-pair post mills, and in the south-west, small one-pair tower mills, and this as probably normal European practice anywhere outside Holland at that date.

JONES And was his Dutch tour before his first windmill?

BUCKLAND I couldn't remember when I as writing this whether he designed the Wakefield mill before or after the Dutch tour. It is one year either way, and I can't remember.

JONES It seems to show Dutch influence in some ways, but it is not copy of a Dutch mill.

BUCKLAND Remember he saw the Dutch mill books before he went. In the acount of his tour he says time and time again, "I saw a turnabout type drainage mill", and so forth, "exactly to the Dutch mill books".

PLUNKETT How did he come by these books? They must be somewhat rare.

BUCKLAND I wonder where he could have seen them. I doubt if he could have afforded them himself.

PLUNKETT Who would have brought them into the country? Would it have been one of the universities?

BUCKLAND I think they would have been in private ownership, but I don't know who would have bought them. One of his contacts in the Royal Society perhaps? But them, it as about this time that he became a fellow. Or perhaps one of the gentlemen about Leeds may have had them? I don't know.

JONES In his designs, did the cant posts come down to ground level, or did he support them on the lower structure?

BUCKLAND They are sprung from the timbering of the mill house. They are not even sprung off the walls of the base.

JONES That is in sharp contrast to Dutch practice, where the cant posts of an industrial mill with working buildings round the base generally pass down through them to the ground. They are not quite the same posts; Dutch cant posts are usually made in several parts.

BUCKLAND I hadn't realised that; I will check with van Zyl, but I thought he showed the cant posts sprung from the roof.

JONES I have seen them run from the ground, and among modern works, Huslage (Windmolens) shows it. He even shows it in a sawmill; the type with a turning cap, here the posts must be sited to allow the carriage through. This has a bearing on whether Smeaton was copying Dutch practice.

BUCKLAND I feel sure he didn't; they are very much his own work.

A BRYAN I suggest these open-frame mills were not designed to last very long; 50 years at the outside. We tend to look on these old mills as a thing to restore and keep into the future, but when they were used industrially - in the 1750s, say - they were in a risk business. They built a mill for a price they could afford, and then it had to do its job and earn its keep. They weren't concerned about achieving a very long life. Against this, the open frame construction starts to mean something. It saves money.

BUCKLAND It saves money; it also wastes a lot of space in the tower. All that space has to be provided, and you can do nothing with it. You then have to built your large brick mill house beneath it to house the machinery, some of which could have gone in the tower.

A BRYAN Yes, but this house is a convenient shape; it is approximately a cube, with clear floor areas to work on, whereas the upper floors of most smock mills give appalling working conditions.

BUCKLAND You have very limited bin storage space in these two floors. In Chimney Mill, Smeaton followed watermill practice and placed four pairs of stones down on a hurst, sprung off the ground floor, so that the meal was bagged at floor level and the only storage space was on the floor above that. You have this very tall tower - about the size of Cranbrook - and yet all the working parts are crammed right down in the base of the thing.

A BRYAN Yes, but by doing that you are taking all the stress and vibration out of the structure and putting it lower down; into the foundations and kept out of the walls, so the hurst and gearbox idea was very sound in principle. I believe the reason it wasn't used more widely was the small size of some of our mills; there just wasn't room for that sort of thing. For example, Shiremark mill had the gearing in a hurst, but it took up a lot of space in what was a fairly spacious tower. This mill also dated from the 18th century.

BUCKLAND Can you give me more details on Shiremark? I went over it once when it was very derelict, and I can't recall how the plant was arranged.

A BRYAN It had a brick base and standing on it was a hurst frame which contained the main gearing - the spur wheel and the underdrive gear to two pairs of stones. Above that it continued up as a smock mill,so the eight of the stones was carried directly on the brick base.

BUCKLAND What is the date of Shiremark? 1780s, 90s?

A BRYAN Probably; certainly 18th century. Unfortunately it has now gone.

JONES On the question of durability and value placed on it; Mr Bryan may be right about the English attitude to it, but it wasn't the Dutch attitude. They expected a very stable business which went on into the distant future, so they built to last, and they have many very old mills standing today. Their designs took care over durability and maintainability. They though alway about repair, and keeping it working. This shows in their attitude to later improvements. In the early 19th century they looked at the English inventions, and for the most part, didn't adopt them. The only one they adopted with any enthusiasm was the cast iron windshaft, and the only improvement they made themselves was the hollow iron sail stock. These were both aimed at durability, wheras most of the English improvements were for working convenience. A typical late English windmill is very lightly built; not made to last, and only by chance and modern conservation have any done so.

BUCKLAND The Dutch also had access to large timber, which most other countries did not. It is notable that most of their mill structures are over-strong. In the 18th and 19th centuries, nowhere else could you use timber so unscientifically as the Dutch did. You couldn't have enormous sail spans of 27 m where each pair of sails was a single massive stock. The other factor in their longevity was that the Dutch thatched their towers. That was extremely weatherproof, whereas when the English built smock mills they covered them with weatherboarding, without ever solving the problem of weatherproofing the angles.

Notes.

1 See Henry L Douch, Cornish windmills, Truro: Oscar Blackford Ltd, [1963]; Walter E. Minchinton, Windmills of Devon, Exeter: University (Dept. of Economic History) and Exeter IA Group, 1977; Alfred J Coulthard and Martin Watts, Windmills of Somerset, London: The Research Publishing Co, 1978; Laurence Turner and Martin Watts, "The small tower mills of the British Isles", The International Molinological Society (TIMS), Trans. 4th Symp., Matlock, England, 1-8 September 1977, London: SPAB for TIMS, 1978,p.55-74.

2 See Trans. Newcomen Soc, xii (1968-9) pp163-4.

3 Royal Society, Classified Papers, 1660-1740, III (1), Mechanicks. By Mr Bruce (David Bruce MD, an original Fellow of the RS, elected 20 May 1663). Read 7 January 1662 (i.e, 1662-3). These must be his lecture notes. He deals with horse mills, a motor of some importance in the western half of the Netherlands. Pehr Lindberg's (Linperch's) Dutch mill book of the (?1690s) and 1727 contains several horse mill designs. These included, says Bruce, mills with screws smaller than the windmill ones, for draining ditches, and others with rectangular pieces of wood drawn through sloping rectangular tubes by endless double chains. Other horse mills made thimbles, "where One horse keeps 20 men at worke"; churned butter; ground lead ore, and cement or tarras by means of two edge runners; ground corn; made oil; and polished marble. And, he concludes:

> The most considerable of them all is that which they call a Moeder mill or mud mille which is a very large boate wherin they have stableing for 4 horses and lodging for two or 3 men. In this boat there is a horsemille turned by two horses at a tyme which by a double chaine and quadrangular bords brings through a quadrangular tube the mud from the bottom of the water and casts it in another boat which carryeth it a [sic] land. These they use at Amsterdam to deepen the places where they have their shippes and the earth that is gotten by this means they use for raising high the gro[u]nds upon which they now build.

4 The date of the superlative smock corn mill, a work of real virtuosity, with a sail span of 100 Amsterdam feet (28.3 m or 93') in Pehr Lindberg,

Architectura Mechanica. Moole boek ..., Amsterdam, n.d. (?1692-5). (The plate is reproduced in Trans. Newcomen Soc, iii (1922-3)).

5 John Smeaton's diary of his journey to the Low Countries, 1755, London: Newcomen Soc, 1938 (Extra Publication No 4). It is more-or-less true to say that this design stasis continued for two centuries, till the Dutch windmill's obsolescence at the end of the 19th century. A German millwright, one H.K, wrote in 1864:

> The windmills of Holland earlier served as a model for our millwrights, and notwithstanding that latterly they have not been improved, there is much in their construction that is interesting and instructive for us.

Holland, he added, has the greatest number of the most complete windmills;

> also, in recent times England has earned merit in perfecting them. The windmills of northern France deserve little consideration as they are generally inferior to our German mills.

(Die Muhle, Leipzig, 1. Jg, 1864, pp.143-4). A direct recent result of the publication of Smeaton's diary was the week's holiday that the late Mr. John Russell of Cranbrook mill and Mr P Davies, now of Cheriton, Folkestone, spent in Holland in 1938. Neither had a word of Dutch, but Mr Russell took photographs of Cranbrook mill with him; and by pointing to a photo and then to himself, gained them ready access to the mills they visited (per Mr Davies, November 1985).

6 Designs, i, ff.1v-3v, 4.

7 John Smeaton, "On the construction of windmill-sails", Phil. Trans. li/1 for 1759 (London, 1760), p168 (and passim).

8 Trans. Newcomen Soc, xxiv (1943-5), p.149.

9 Tom Kovarik, Charles Pipher and John Hurst, Wind energy, Chalmington, Dorchester: Prism Press, 1980, p.75, using the formula $P = 0.00246\ D^2V^3$, where P is power in watts (theoretical maximum), D is the sail span in feet, and V the wind-speed in mph.

10 "Prinsenmolen"-Committee, Research inspired by the Dutch windmills, H Veenman en Zonen-Wageningen [1958 or 9], p.26. TNS, loc. cit, says that "one can only say, quite approximately, that most mills attain their normal speed in winds ranging from 12-14 mph (5.4-6.3 m/s).

11 Smeaton to Carron Co, Austhorpe, 7 February 1782:

> ... I must add, that in the year 1755, that is, 27 years ago, for the first time, I applied them [loose grammar, either meaning large cast iron "utensils" generally, or a windshaft and oil press specifically] as totally new subjects, and the cry then was, that if the strongest timbers are not able for any great length of time to resist the action of the powers, what must happen from the brittleness of cast-iron? It is sufficient to say, that not only those very pieces of cast work are

still in work, but that the good effect has, in the north of England, where first applied, drawn them into common use, and I never heard of any one failing.

(Smeaton, Reports (1837), i, p.274. Reference from Rex Wailes, "Notes on the windmill drawings in Smeaton's designs", Trans. Newcomen Soc, xxviii, (1951-3), p.240).

12 Smeaton, Reports (1837) i, p.250, plates 28, 29; Paul Norman Wilson (later Baron Wilson of High Wray) (1908 - 24 February 1980), "The waterwheels of John Smeaton", Trans. Newcomen Soc, xxx (1955-7), p.33 and plate 11. This outstanding paper stimulated my interest in Smeaton. The Carron plant is in Smeaton's list of mills executed (Reports (1837) ii, p.423). See also, Denis Smith in Alec W Skempton (ed.), John Smeaton, FRS (1981), pp.64-69.

13 Institution of Civil Engineers, Smeaton's press-copy out-letter books, iv, p.146 (Smeaton to Walton jr, London, 26 May 1785). Walton jr. is his close friend Nicholas Walton, who had been co-Receiver with him on the Derwentwater estates in Northumberland and Durham, forfeited in the 1715 Rebellion and assigned to Greenwich Hospital for its support. Warren water corn mill, Northumberland, was a mill on this estate.

14 Smeaton designed Warren mill in 1783, with a wooden layshaft parallel to the wheelshaft, driving 3 pairs of stones, and with a 2-step geared upright shaft to a barley mill (Designs, i, f.114). The wheelshaft wwas cast at Carron, and the mill was set to work on 5 May 1785. On 22 December 1786, the shaft broke and was replaced by a wooden one (Designs, i, f.116, a note, copied accurately enough in Dickinson and Gomme's bad catalogue of the designs (1950), p.21; ICE letter books, iv, pp.214-5, Smeaton to Walton, Grays Inn, 13 November 1785; iv, pp.147-8, Smeaton to Barnes, Grays Inn, 30 May 1785). Smeaton had the wheel flanges, or boxes, cast integral with the shaft. The shafts failed there because of honeycombing in the castings. Smeaton could see no way round this but to cast them hollow with a bigger diameter, so giving them greater strength by the twist or torque of the shaft acting further out, in the places where the casting was likely to be imperfect (Smeaton's ICE letter books, iv, pp.144-6, Smeaton to Walton sr, Grays Inn, 26 May 1785). In 1789 he designed a hollow cast iron wheelshaft for G. Shepley's oil mill, Wandsworth. Outside diameter 18" (457 mm); thickness of wall, under 1.2" (30.5 mm), three flanches cast on it. End plates with gudgeons cast separately (Designs, ii, f.25). (This was missed by Lord Wilson).

15 Alec W Skempton (ed.), John Smeaton, FRS, London: Thomas Telford Ltd, 1981, p.191. This is in John S Allen's short, but good chapter on Smeaton's steam engines. The winding engines are dealt with on pp.188-192. A puzzle is that only three are claimed for him: at Long Benton, Walker, and an earlier design at Griff. At Long Benton, one shaft broke; but at Walker, there seem to have been two successive breakages of the same shaft. Also, a second gin as erected there in 17885, based on Smeaton's one. (Letters, passim).

16 Institution of Civil Engineers, Smeaton's press-copy out-letter books, iv, pp.147-8 (Smeaton to Barnes, Grays Inn, 30 May 1785).

17 The earliest postcards of the rebuild show an external ladder to the "buck"; but it leads up to a dummy doorway outlined in the weather-boarding. The radial framing of the roof of the base ends in a central 1 m square framed "hub" where the hollow post once went.

18 Designs, i, f.1v.

19 Institution of Civil Engineers, Smeaton's press-copy out-letter books, ii, pp.152-4, letter of 18 February 1786.

20 Richard Bennett and John Elton, History of Corn Milling, iii, London and Liverpool, 1900, pp.257-263.

21 Designs, i, ff.54-64. Smeaton's second watermill. Low breast wheel. Spurwheel drive, three pairs of 4' (1219 mm) stones on a triangular hurst table, a design peculiar to Smeaton (see Reports (1837) ii, pp.129-30 and plate 16; Trans. Newcomen Soc. xxx (1955-57). p.30 and plate 9). Crash hoist, which took sacks off a barge by the mill up a slide, and vertically to the loft. Two bin floors were, apparently, reduced to one before erection. The soke mill was at the Wakefield end of the medieval bridge across the Calder, and a long angled weir went from it across the river (as at the Dee mills, Chester). Smeaton's rebuild of it is clearly the tall, steep-roofed gable-ended building in an oil painting, assigned to ca 1756-58, reproduced in John Goodchild (compiler), The Development of Wakefield in maps, plans and views, ca 1680 - 1926 (a folder), Wakefield Historical Publications No. 7, 1981, item 5. A windmill (left) is reproduced scarcely visibly. Smeaton's watermill may be part of the mill's ground plan in the 60" OS map, surveyed in 1848 (item 13). A low, small bin-less toll mill on the site is shown clearly in a copperplate by W. Lodge (d.1689), published "in a book" of 1715 (item 1). In 1758, Mr John Smeaton, engineer, said "That he was concerned in some Works at Wakefield Mills in the Year 1754: That the Soc Mill had then Four Wheels, and One new Wheel was then made for Flour on the North Side, and there was Two Fulling Wheels and One Frizing Wheel on the South Side" (JHC, xxiii, p.141b).

22 Wakefield Metropolitan District Archives (Goodchild Loan Collection) (transcript courtesy of Rev. Laurence Turner, September 1984). The fulling side seems not to be mentioned in the purchase of the soke.

23 William S. Banks, Walks about Wakefield (1871), reprinted by Wakefield Historical Publications, 1983, p.102n.

24 Indeed, it seems likely that Smeaton took the idea of a rectangular base housing the plant from the Netherlands. Smock sawmills need a timber run under the tower as unobstructed as possible. The Dutch devised two solutions to this. One was to make the smock hexagonal, so that the only obstruction is the two centrally-placed in-line lower cant posts (Johannis van Zyl, Theatrum machinarum universale: of groot algemeen moolen-boek, Amsterdam, 1761 (a re-issue of the 1st ed. of 1734), Amsterdam mill "t' Fortuyn", driving three saw frames, dated 1734, plates 51-3). But the hexagonal smock is as unpopular in Holland as over here. Of the 9 surviving smock sawmills, only one is hexagonal, and only 5 other smocks are hexagonal (The Dutch mill-survey...., Alkmaar: De Hollandsche Molen, April 1983, p.18, no.29, and passim). The other solution is to spring a

standard octagonal smock tower off the four top cills of a massive timber frame or house, with gently battered sides, forming the central part of a long range of buildings forming the timber run. As shown in the fine Sloterdyk mill "De Ster" (van Zyl, plates 36-8), four of the cant posts are, almost incredibly, sprung almost 1/3 the way along the unsupported length of the two 7.22 m (23'9") long cross cills which span the timber runs. The cill section is ca 355 mm wide x ca 425 mm deep (14" x 17"). There are two timber runs, one very broad and passing under the centre line.

The stamps and edge runners of an oil mill are contained in a similar square timber house with gently battered sides, beneath the stage (van Zyl, plates 9,10); as are the two sets of edge runners of another oil mill (van Zyl, plates 14,15); and are the three sets of fulling stocks in J.H.Harte, Volledig Molenboek, Gorinchem, 1849, plates 45-7). The 1960's reconstruction of the mid-19th century snuff and spice mill "De Ster", Rotterdam, has a two-floored square brick base housing the stamps and edge runners, which is surmounted by the octagonal smock housing the grinding stones (TIMS, Trans. third symposion, Netherlands, 1973, May 6-11 (no place, 1973 or 1974), pp.37-46).

25 Essex RO, Essex in Pictures, Chelmsford: Essex County Council, 1952 (Essex RO Publications, no. 15), plate 9.

26 The drawing is reproduced in Katherine Fry, History ... of East and West Ham, London, 1888, p.141; and in Gustav Pagenstecher, History of East and West Ham, Stratford, 1908, p.68, and see p.67. The Abbey Mills were set between channels of the Lea, and were a wind and watermill complex.

27 See Kenneth G Farries, Essex windmills ..., iv, Cheddar, Somerset, and Edinburgh: Charles Skilton, 1985, pp.36-7, for details and another illustration.

28 Kenneth G Farries and Martin T Mason, The windmills of Surrey and Inner London, London: Charles Skilton, 1966, pp.213-4, plate 112.

29 Jennifer Tann, The development of the factory, London: Cornmarket, 1970, the first double t.p, and pp.151-2.

30 Rex Wailes, The English windmill (1954), plate 11.

31 Thankfull Sturdee, Reminiscences of old Deptford, Greenwich, 1895, plate 49 (c.1840).

32 Designs, i, ff.30, 31.

33 Smeaton, Reports (1837) ii, p.423. Dates added from the Catalogue of Smeaton's designs at the Royal Society, ed. H. W. Dickinson and A. A. Go mme (Newcomen Soc. Extra Publication No. 5, 1950).

34 Designs, i, ff.5v-r, well reproduced in Michael Short, Windmills in Lambeth, an historical survey,London Borough of Lambeth, 1971, p.51, (text, p.50).

35 Designs, i, f.3A. The brake wheel (so named) was 8'7" (2620 mm) in

diameter, 60 cogs; the wallower (called the crown wheel) had 49 cogs, a ratio of 1:1.224. The sail is quite broad by latter-day practice. See note 38; also, Vincent Pargeter, "Kentish windmill sweeps", Trans. 4th Symposium ... (as note 1), pp.236, 239 (lower diagram): Margate smock, 66' (20.1 m) span, 6'6" (1.98 m) overall width; a typical 70' (21.3 m) sail span has an overall width of 7' (2.13 m). For more details of the Barking mill, see Roland Smith in Kenneth G Farries, Essex windmills ..., iii, Edinburgh: Charles Skilton, 1984, p.29.

36 Reproduced in Short, loc. cit.

37 Scaled up from the reproduction of the mill's elevation in Rex Wailes, "Notes on the windmill drawings in Smeaton's designs", Trans. Newcomen Soc, xxviii (1951-53), plate 32 (Designs, i, f.1v).

38 Scaled up from reproduction in ibid, plate 34 (Designs, i, f.8r). The 70' (21.3 m) span double shuttered patent sails on Upminster smock mill have rectangular frames and an overall width reducing from 7' (2.13 m) to 6'6" (2.04 m) at the points). See the scale drawing in Kenneth G Farries, Essex Windmills ..., ii, London: Charles Skilton, 1982, p.59)

39 As note 34, plate 35 (Designs, i, f.9r)

40 Reports (1837) ii, pp.120-121. I shall deal with his sail weathering separately.

41 John Mayhall, The annals and history of Leeds ..., Leeds, 1860, pp.153-4. (Not in the extracts from Leeds papers in Publications of the Thoresby Soc, xxxviii (1937), Leeds, 1938).

42 Institution of Civil Engineers, Smeaton's press-copy out-letter books, i, p.16 (Smeaton to Smith; semi-legible)

43 Smeaton, Austhorpe, 7 February 1782, to Carron Co, in Reports (1837), i, p.274. As printed, reads "windmill, axis, and oil-press". Immediately preceeds the passage quoted in note 11.

44 Institution of Civil Engineers, Smeaton's press-copy out-letter books, i, p.12, Smeaton to Gosling, Austhorpe, 15 January 1782, "the finishing and Establishing an Oyl mill, and its Conveniencys for my son in Law"; ibid, i, p.40, Smeaton to Seton, Austhorpe, --, 1782 (between letters of February (?) and May 1782), your letter of 5 April arrived "when I was in the Extremest degree of Hurry, in compleating An Oyl mill that I was then building upon my own Estate".

45 Ibid, i, p.69 (Smeaton to Hartop, Austhorpe, 24 June 1782). If Smeaton thought so highly of him, finished drawings may never have existed - Smeaton may only have given him the tooth numbers, the gear wheel sizes and the overall dimensions. In 1785, Smeaton addressed him as "Friend Jonathan", and gave him advice on the cylinder size for a returning engine with a tiny 5'6" (1676 mm) lift (ibid, iv, p.134, dated from 2 Holborn Court, Grays Inn, 16 April 1785). None of the letters in notes 42-45 names the mill, but it is undoubtedly Sykefield.

46 ibid, i, p.121. Smeaton added that he was ordering the stove from London

for speed; otherwise he could get one from Rotherham, where it was called a "Skinners Cockle", as a special order.

47 See Charles Hadfield and A. W. Skempton, William Jessop, David and Charles, 1979

48 Interpreting Eastburn's letter in Designs, i, f.4v.

49 BM add MS 33272 f.8v (Sir Charles Blagden to Banks, 4 September 1786).

50 Institution of Civil Engineers, Smeaton's press-copy out-letter books, iii, p.41 (Smeaton to Aubert, 16 March 1788).

51 Ibid, iii, p.72 (Smeaton to "My Dear Friend", Austhorpe, 10 December 1789)

52 Original of will and codicil at Borthwick Institute of Historical Research, York. Will of John Smeaton of Grays Inn, London, Civil Engineer, dated 16 April 1792, proved, with codicil, December 1792. His executors are his daughters: Ann, wife of John Brooke, and Mary, wife of Jeremiah Dixon. The codicil has a very shaky signature, done with the left hand, as he was paralysed on his right side. He died on the 28 October 1792, five weeks later.

53 Ibid, i, p.16.

54 Ibid, i, p.17 (and see index to volume). The first two fifths are printed in Reports (1812) ii, p.396, and in the 1837 edition, ii, p.108.

55 Ibid, i, p.23 (Smeaton to Carron Co, Austhorpe, 28 January 1782; semi-legible, several words doubtful). Smeaton had already designed for William Smith a water snuff mill at Chimney Mills in 1781 (Designs, ii, ff.19-23) (not Chimney windmill, as it is listed in the very careless catalogue, ed. H. W. Dickinson and A. A. Gomme, Newcomen Society, 1950). It perhaps replaced an existing one, and was just completing about January 1782 (letter books, i, p.16, Smeaton to Smith, Austhorpe, 20 January 1782). Smeaton was designing a tobacco mill in addition to it in December 1782 (letter books, i, p.129, Smeaton to Smith, Austhorpe, 26 or 28 December 1782). On April 1, 1788, the whole tobacco and snuff manufactory, its stock-in-trade, "and all the valuable machinery" were burnt down (John Sykes, Local records ..., i, Newcastle-upon-Tyne, 1833, reprinted 1866, p.346). It was clearly rebuilt, as Eneas Mackenzie's history of Newcastle, i (1827), p.194, mentions it as standing. A brewery was later built on the site, replaced by coachworks in 1932, which (July 1984) were to be replaced by housing. The chimneys used for drying the tobacco for snuff are the source of the "Chimney" in the name (letter, Mr. Thomas Falconer to author, dated from Chimney Mill, 3 July 1984).

56 The fate of Smeaton's built-up beams for atmospheric steam engines was similar.

57 Letter and sketch from Mr. Thomas Falconer, Chimney Mill, Claremont Road, Newcastle-upon-Tyne, NE2 4AL, to author, 27 July 1984.

58 At Hildenborough, Watts Cross, Kent, an older mill (demolished 1961), each cant post was tenoned into the junction of two cills. The tenon, to align

it with both abutting cills, had an obtuse angled bend in it. The cills were prevented from working apart by a wrought iron strap with fearsome iron spikes projecting from its face. These were driven into the cills' outer faces, firmly anchoring the strap. On West Kingsdown smock mill, Kent, moved to its present site in 1880, the cant posts are housed in cast iron boxes bridging each pair of cills and bolted to them.

59 My best interpretation of it from the vertical section, as reduced by Farey for Smeaton's *Reports* (the original plates as reused in the second edition of the *Reports*, ii, London, 1837, pp.108-9, and plates 10, 11; whence all my notes from them).

60 Institution of Civil Engineers, Smeaton' press-copy out-letter books, i, pp.19-20 (Smeaton to Wedgewood, 26 January 1782)

61 The ratio on the large fan of Upminster smock mill is 1816:1 (Farries, op. cit, ii, p.56).

62 John Nelson, *History* ... *of St. Mary Islington* (1811), p.195.

63 Wailes, *English Windmill* (1954), plate 32. By 1853, both had become sail-less storehouses and the white calx was ground by a 20 hp steam engine (Thomas Cromwell, *Walks through Islington* (1835), pp.108-9). No trace of either survives.

64 *Svedenstierna's tour* (David & Charles, 1973), p.103.

65 See the excellent photograph of the first mill reproduced in Norman Plastow, "Wimbledon Common Windmill", *London Archaeologist*, ii/13 (Winter 1975), and offprinted; also Wailes (1954), p.83 (date).

66 Institution of Civil Engineers, Smeaton's press-copy out-letter books, i, p.146 (Smeaton to Smith, Austhorpe, 15 January 1783).

67 *Gent. mag*, July 1783, p.631. He is William Smith, tobacc oni st, Side, in *Whitehead's Newcastle and Gateshead directory for 1782.3.4*, Newcastle-upon-Tyne, p.38. In 1787, Smith has gone, but Matthew Harrison & Co, tobacconists and tea-dealers, Side, appears (William Whitehead, *An account of Newcastle upon Tyne*, N-upon-T, 1787, p.70). Eneas Mackenzie, *A descriptive* ... *account of* ... *Newcastle upon Tyne*, i, N-upon-T, 1827, p.194, says "the late Mr. Smith" built the tobacco and snuff works at Chimney Mills, then owned by his son-in-law Mr. Matthew Harrison. "Here are also two corn windmills" he adds. Evidently, Chimney windmill was sold out of the familly in 1783.

68 *Newcastle chronicle*, 23 August 1783, cit. *Newcastle weekly chronicle*, 18 February 1928; photocopy of MS auction sale map (lot 1, mill field, and mill). (Both courtesy of Museum of Science and Industry, Blandford House, W. Blandford St, Newcastle-upon-Tyne NE1 4JA, who kindly sent me photocopies of their Chimney Mills file, June 1984).

69 *Newcastle chronicle*, 1 November 1783, cit. as note 68.

70 Photocopy of Rennie's MS note, from (photocopy of original) in Chimney Mills file (as in note 68). One page, headed by Rennie, "Newcastle upon

Tyne", and endorsed "Rennies Notes". (Doubtless copied from one of his numerous unpublished notebooks, now in the National Library of Scotland, Edinburgh).

71 John Robinson, The articles steam and steam-engines, written for the Encyclopaedia Britannica ... With notes and additions, by James Watt, Edinburgh, 1818, p.137n. Note on Albion Mills from the same page, and plates 5, 7, 8. John Mosse says that the millwork was not originally designed by Rennie; but that he greatly improved it (Trans. Newcomen Soc, xl (1967-8), pp.50, 58). Mosse is wrong though in dismissing the millwork as "the usual water-driven type, nothing novel".

72 Smeaton's Carshalton watermill (most probably gone) was a tall, very fine functional building with gabled roof, and two internal breast wheels placed across it centrally and side-by-side. Upright shaft drive with lantern wallower and deep double-cogged great spur meshing with lantern nuts (Designs, i, ff.94v - 102; the wheel drawing reproduced in Trans. Newcomen Soc, xxx (1955-57), plate 57). To Smeaton, it, with Warren mill, Northumberland, were "two of the Largest and Best mills, whose construction I ever directed" (ICE letter books, iv, pp.214-5, Smeaton to Nicholas Walton, Grays Inn, 13 November 1787). But Rennie wrote to Matthew Boulton, 28 January 1785: "I must confess I am not very much satisfied with her; indeed I allow she had an excellent waterwheel but her inner work is extremely confused and ill executed" (Jennifer Tann, The development of the factory, London: Cornmarket, 1970, p.95).

73 Tann, op. cit, p.97 (Watt to Boulton, 20 April 1786).

74 Under millers, directories list a John Douglas, Chimney Mills, and James Read, Chimney Mills, in 1847; Thomas Meek, 7 Chimney Mills, in 1857-8; Rogerson & Dodd, Chimney Mills (John William Rogerson, Mill house, Chimney Mills, and William Pringle Dodd, 32 Claremont Road), in 1888. (White's Newcastle, 1847; Ward's North of England, 1857-8; Ward's Newcastle, 1888).

75 These two paras entirely derived (except 1933, from Trans. Newcomen Soc, xxviii) from the Chimney Mills file (as note 68); and from material and letters on the mill kindly sent me by Mr. Thomas Falconer RIBA of Falconer Associates, Chimney Mill, in July 1984 - in particular, a print of a first rate photograph of the mill in working order, comparable to that of the Sandhurst five-sailer in F. C. Clark's Kentish Fire, Rye, 1947.

76 Letter, Mr. Falconer to author, 27 July 1984.

77 Designs, i, f.5r (the skew gear, probably Stepney mill), 16v - 18r.

78 Institution of Civil Engineers, Smeaton's press-copy out-letter books, i, p.158 (dated from Austhorpe).

79 Ibid, i, p.168 (Smeaton to Landell & Chambers, Austhorpe, 9 June 1783).

80 Ibid, i, p.170 (Henry Eastburn to Landell & Chambers, Austhorpe, 9 June 1783).

81 Ibid, i, pp.172-3, n.d.

82 Newcastle magazine, vi (1827), pp.280-3. (There is a John Davidson, corn miller, Union mill, Stepney fields, in Francis White & Co's General directory of ... Newcastle-upon-Tyne, Sheffield, July 1847, p.171).

83 Reproduced in Trans. Newcomen Soc, xvii (1936-7), plate 21. Bradwell tower mill, Bucks, is or was a nice example of this stage of development, as are Wheatley tower mill, Oxon (built 1784), Bembridge tower mill, Isle of Wight, and Lacey Green smock mill, Bucks. The mid-17th century date now claimed for the last mill may be doubted.

Fig. 1. Chimney Mill, Newcastle-upon-Tyne, in its latter working days (photograph by courtesy of Mr Thomas Falconer)

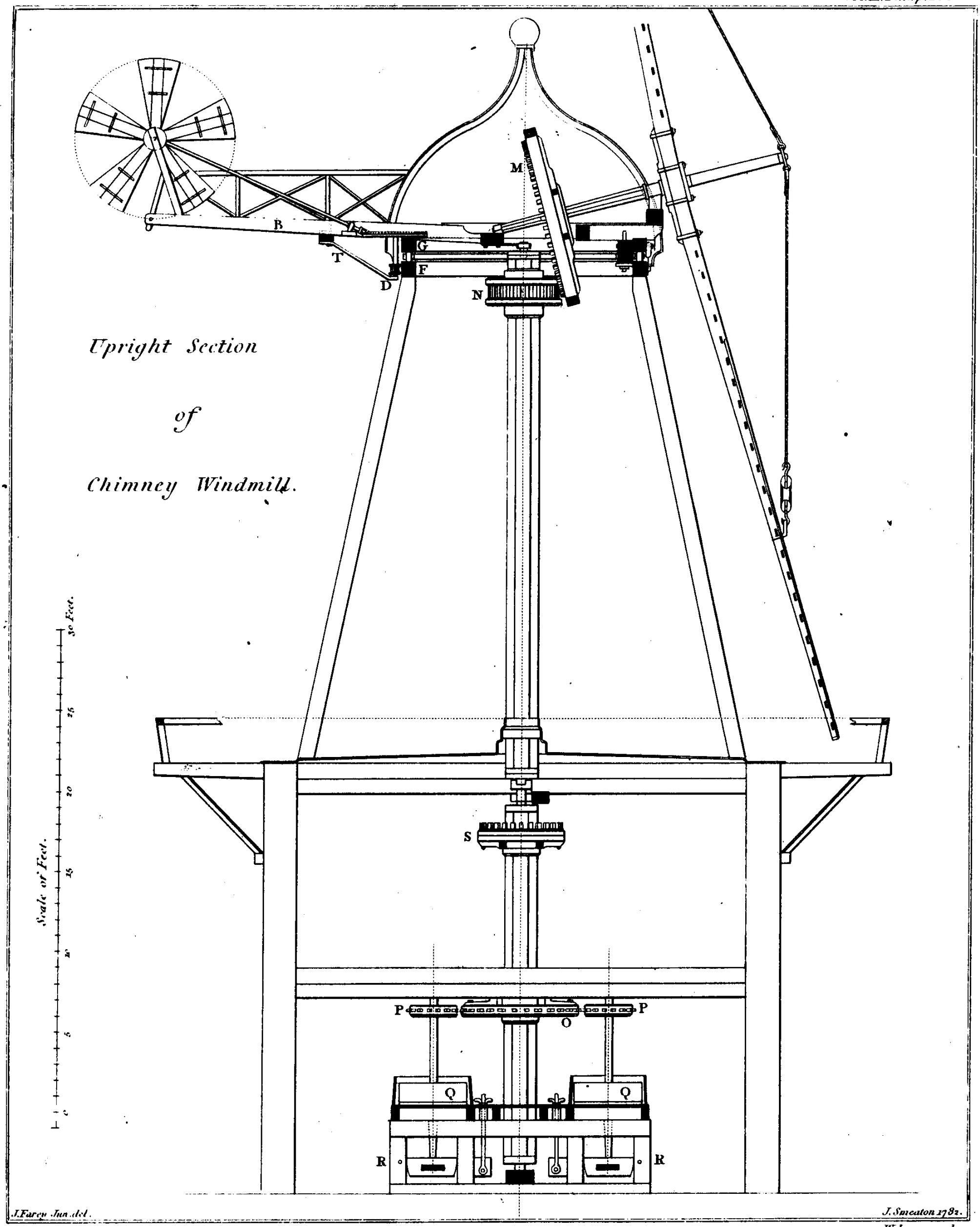

Fig. 2. Chimney Mill, vertical section (Smeaton's Reports).

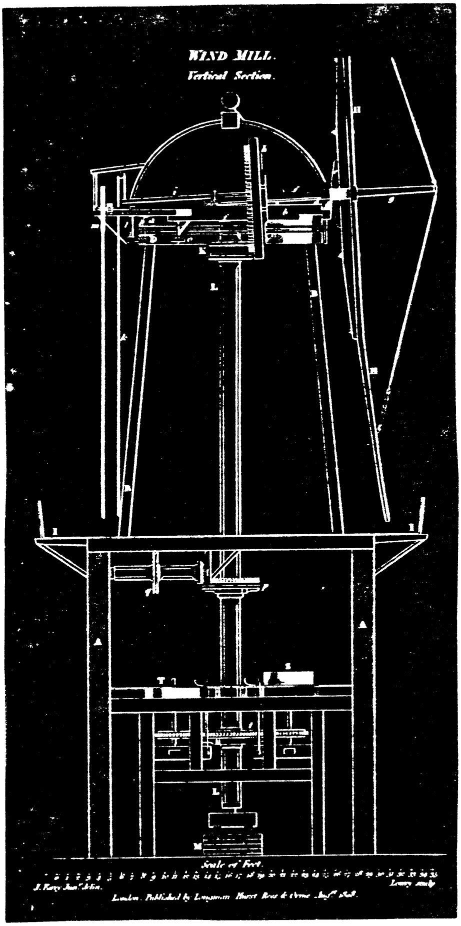

Fig. . Wakefield mill, redrawn as a corn mill by John Farey jr. in 1809. He has made the ogee cap a dome, hung the brake rope externally, modified the endless rope winding tackle and the shape of the rear extension housing it, made the bowsprit longer, and raised the level of the first floor in the mill house. (William Nicholson, British Encylopaedia (1809), art. "Windmill").

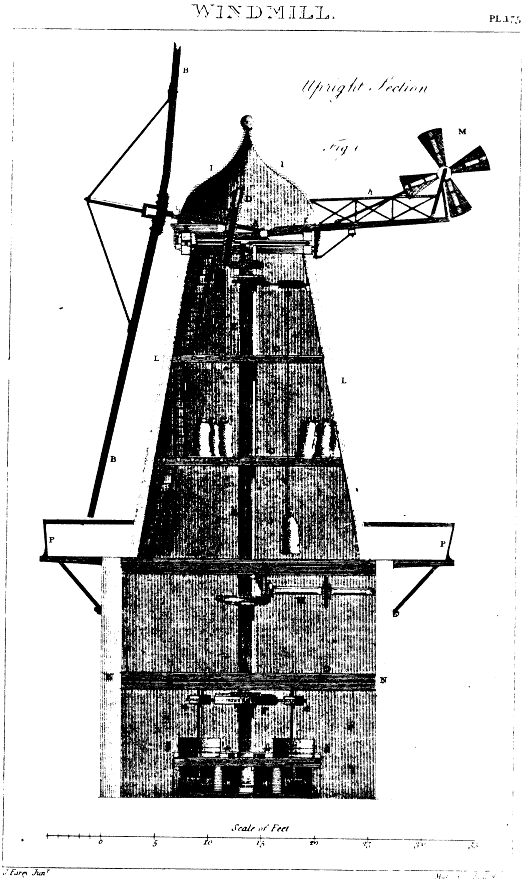

Fig. 4. Chimney Mill, as misunderstood and redrawn by Farey with floors in the smock and 4-bladed fan (Pantalogia, xii (1813), art. "Windmill".

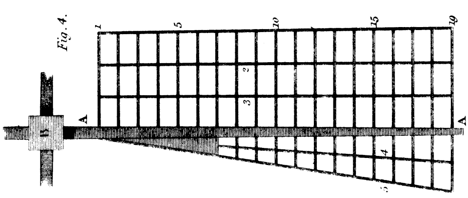

Fig. , Smeaton's Splayed windmill sail. (Abraham Rees, Cylopaedia (1819), art. "Windmill").

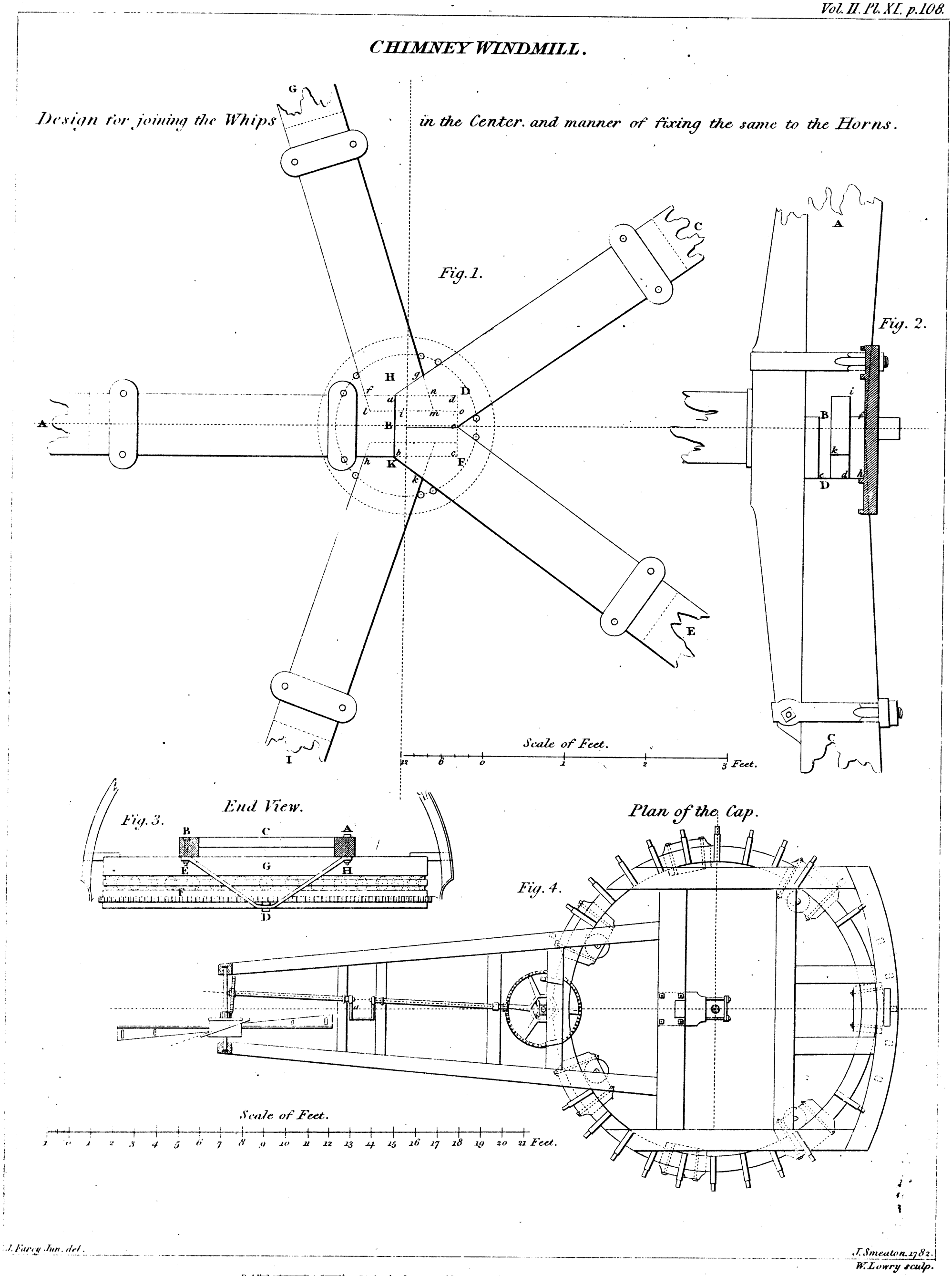

Fig. 6. Chimney Mill details (Smeaton's Reports).

Fig. 7. Chimney Mill, 14 September 1963 (photo Rev L. J. Turner)

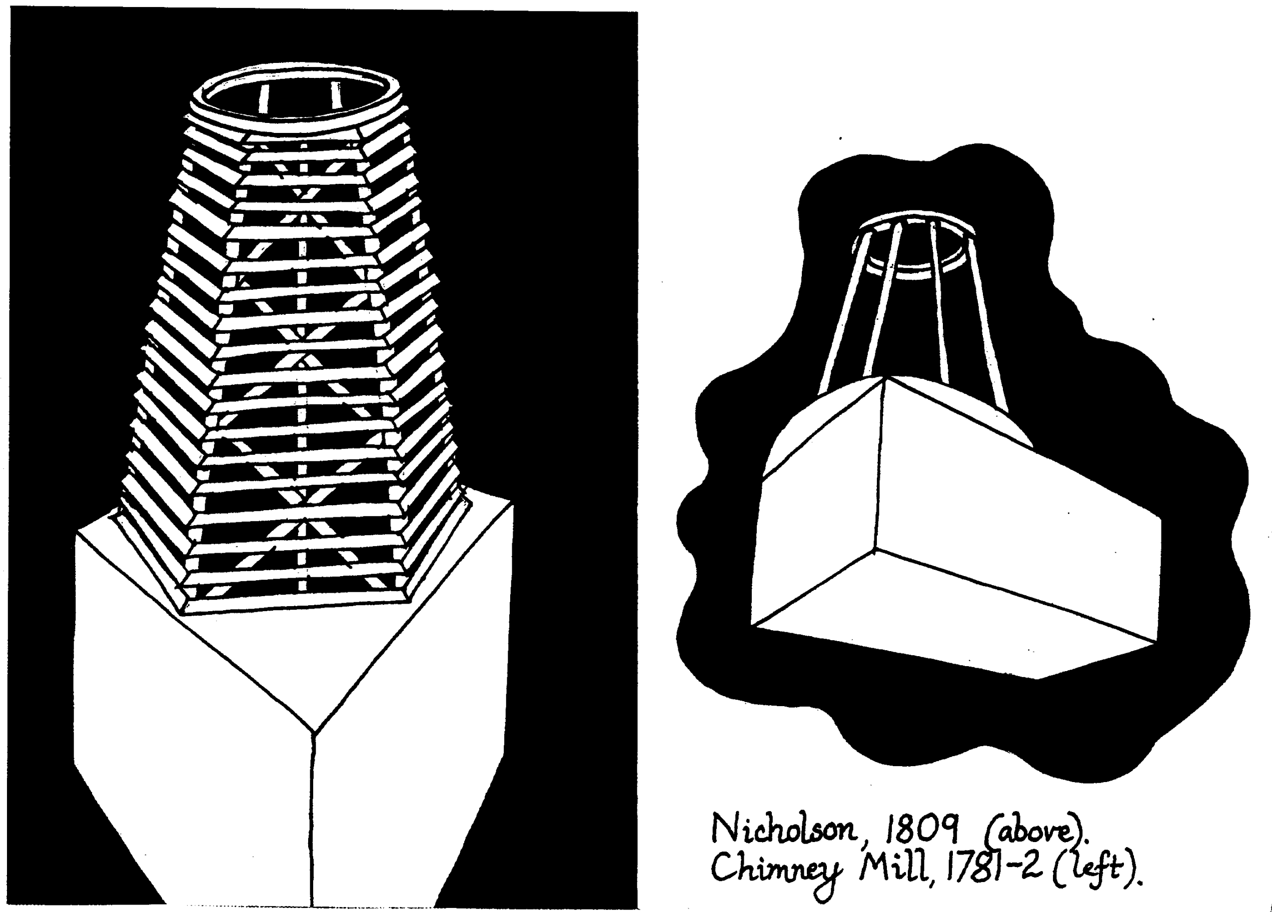

Fig. 8. Schema to show Smeaton's design concept.