VARIABLE MILL SAIL WEATHER: A DESCRIPTIVE SKETCH

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The Netherlands

1) 16th - 17th centuries

Variable weather (the propellor-type twist of a mill sail) seems to have originated in the Netherlands. Sails with "double curvature" or "zeeg" are (I read) shown in the patent granted by the States of Holland and West Friesand to Cornelis Dircksz Muys, town carpenter of Delft, on 31 October 1589, for a drainage windmill (1). The design of 1607-08 of the smock wind engines for draining the Beemster lake, by the great Jan Adriaanszoon Leeghwater (1575-1650), probably (within the draughtsman's limitations) shows variable weather. Also, it was specified for them (2). At the same time it is caught clearly on a Flemish post mill landscape of Jan Breughel I, dated 1607 (3). Jan van de Velde's etching "Summer" of 1617, shows it with certainty (4). And Rembrandt van Rijn, in his consummate etching dated 1641 (145 mm x 209 mm), of a Dutch smock mill, still partly primitive and quite small, has caught to perfection the subtlety of the dramatic curvature of the flattening of the weather as it sweeps out towards the point (see Fig 1).

A little later on, we have several good examples in the sketches and paintings of the Haarlem-born landscape painter Jacob van Ruisdael (c.1628-1682). Three early black chalk sketches of c.1646 of post mills show variable weather, particularly nicely on the sails of the quite small post mill in the one titled "Landscape with a windmill, and a cottage on the left." (5). It is also shown clearly on the Netherlands post mills in his paintings, "Landscape with a windmill," of 1646 (6), and "Evening landscape; windmill by a stream," of c.1646, the latter in the Royal Collection (7). And his very fine "Landscape with windmills," a view near Haarlem, of c.1650-52 (Dulwich Picture Gallery, no. 168), shows it well, both on the broad, squat, North Holland inside-winder smock in the background, where it is caught to a nicety on the upper left sail, and on the small battered, inside-winder tower (corn) mill in the foreground (see Figs 2 & 3). Somewhat later still, the twist on the sails of a wipmolen is also shown nicely in the "Fishing on ice" by Abraham van Calraet (Kalraet) (1642-1722), (Dulwich Picture Gallery, no. 181). See Fig 4 (8).

The sails of all these mills lack leading boards, and all (including, most probably, Rembrandt's sails, which lack sail cloth) have a single cloth spread over the stock from the broad trailing to the narrow leading side. All have the same weather on both sides of the stock.

2) Lindberg, ?1690's

The Stockholm millwright, Pehr Lindberg (in Dutch, Linperch) visitd the Netherlands more than once between c.1685 and 1692, chiefly to learn about mills. As a result, he drew detailed elevations and plans of Dutch wind and horse mills. They (and a few Swedish mill drawings) were engraved and published at Amsterdam, probably in the 1690's (9), and were republished there from the same plates in 1727 (10).

Plate 11 of his book is a scale of sail weathering for mill sails spanning 72' 3" English (22.1m); see Fig 5. This would be a normal long span by 19th century English standards, and is a mean long one for the Netherlands around 1700. The 28 bars are spaced at 1.25 Amsterdam feet centres (354 mm), giving 27 spaces and a sail frame length of 32.5' English (9.91 m). From heel to point the weather runs:

Bar No.	Angle of weather	Spaces between bars	Twist	Average rate of twist per space
1	27			
1 (sic)	24.5			
		9	5	0.56
10	22			
		4	4.5	1.125
14	17.5			
		4	5	1.25
18	12.5			
		4	5.5	1.375
22	7			
		4	7	1.75
26	0			
		2	-3	1.5
28	3			

The total twist is 30 and 27. The average rate of twist/space is 1.11 and 1.02. The heel weathers are pronounced ones: doubtless they are for the outer and inner pairs respectively. From the maximum heel weathers of bars one, there is a very slight rate of weather reduction of 0,56 and 0.27/space of 13.9" English, for precisely one third of the sail frame; and thereafter to the point, a dramatic and fairy constant rate of weather flattening out of the twist, averaging 1.3/space, ending in a negative tip weather. This is a rate of change of weather 4.8 and 2.4 times greater than that of the inner third. The inner one-third of the sail has 5 and 2.5 of twist, while the outer two-thirds has 25, or 83.3% and 90.9% of the total twist.

This scale is for laying out the mortices to establish the weathers of eight key bars, drawn as a series of 1' radii springing from a point near one edge of the trailing face of the stock. Lindberg gives the construction rules for drawing it too. No measurement of angles is involved, nor are any given. Jacob Leupold observed of the scale in 1724, that "on what it is based, or why, the author says nothing"; but Lindberg's book, like its successors, is purely descriptive and not explanatory.

The stock is supported off the ground on five short cross baulks, with a side face of it upwards (see Fig 7). A line is marked along this face, 3/4" from one edge, for one half of the stock. This is the line of the mortices for the 28 bars on the trailing side of the stock, and is calibrated for them. A bevel (a carpenter's tool comprising two straight edges hinged together), its moveable arm 1' long, may be aligned against each radial weather angle of the scale. Then: lay the base side of the bevel flat across the stock at the heel bar position, with the junction of its two arms on the 3/4" line. Open it till its hinged arm is aligned with the heel bar radius of the scale, and bore the stock right through at that radius angle. Repeat this operation for the point bar. Then drive a straight stick or rod 1' long into the point mortice, and tie a thin cord to it. Then set the bevel for the bar 10 radius, place its base side flat on the stock at the bar 10 position, bore a hole at this alignment, drive another stick in, and tie the cord first to this stick, then to that in the heel mortise (sic). In this manner, proceed with bar mortices 14, 18, 22, 26; the cord will show you if you have bored the angles correctly. Thereafter, the rest of the mortices are bored "according to the cord and the line" (the 3/4" line marked along the stock), which determine their weather angles and positions. For longer or shorter sails, keep the same twist, but vary the total number of bars. I presume that Dutch millwrights kept such a scale of weather radii as Lindberg gives as tools of their trade; one of which he had copied.

Lindberg's drawing shows rods in mortices 1, 10 and 28, with a cord stretched along them. The other four key mortices are indicated only by straight lines, not rods; but rods must be meant, for at mortices 26 (for the bar in the plane of rotation) the line is shown braced to the stock, and two millwrights are shown standing, boring mortices intermediate to them. (The seven rods must be removed for the stock to be turned over to bore the mortices for the opposite sail. One sail frame may then be assembled on the ground, but the bars of the other can only be driven when the sail stock is being mounted, as the photographs in Rex Wailes, Windmills in England (1948), p.34, show).

Lindberg makes no mention of a lead board, or of the leading side. Nor does he draw a mill sail anywhere. But his brief explanations for: (1) the 1692 oil mill of plates 1-5, say that the stock spans 76 Amsterdam feet (21.5 m), and has sail bars 7' (1.98 m) long, 14" (330 mm) (of which) project on the leading side in order to lay the (lead) board on them; and for (2) the superlative 1685 smock corn mill of plates 15-16, say its stock is 100 Amsterdam feet long (28.3 m), and the overall sail width is 7' 3" 2.05 m), 15" of which is to lay the (lead) boards on.

3) 18th Century and Later.

In 1734 appeared the two indigenous Dutch millwrighting books of Leendert van Natrus et al, and of Johannes van Zyl. A second volume of van Natrus was published in 1736; both volumes were quite shortly re-issued. A promised second volume of van Zyl never appeared, but the one volume (the size of both volumes of van Natrus combined) was re-issued in 1761 (12).

Van Zyl's plate 47 is of scales of weather (drawn as in Lindberg, except that the plane of rotation is shown as a dotted line without a bar number) for 25 and 30 bar sails. Scale 3 is for a 25 bar sail frame, 9.27 m long, with 25.25 of weather, declining from 20 at the heel to -5.25 at the tip, such that 1/3 of the twist is at the inner 3/5 of the sail, and 2/3 of it is in the outer 2/5, which therefore has an average rate of twist nearly three times as great as the inner 3/5. The maximum weather reduces gently for 3/5 of the sail, when its flattening out accelerates to a near propellor-type twist ending smartly 5 over the plane of rotation. His other three scales are broadly similar, and have twists of 26.25, 28, and 29. The least twist and greatest weather on Lindberg's sail is retained for under half the length, but on van Zyl's sails it is retained for over half their length. So the zone of transition between the gently and the strongly twisted parts rolled down the sail to its modern position between the 1690's and the 1730's.

Leendert van Natrus, (1) plates 8 & 9, and (2) plate 5-6, has three sets of sail weathering, basically alike. All have negative tip weather, but differ from van Zyl in that the maximum weather is at bar 5, not at heel bar 1, giving a gentle convexity or bellying to the sail. The bellied form must have existed in parallel with the unbellied before the 1690s: Rembrandt's etching of 1641 would seem to shown it clearly. It is perhaps shown on Ruisdael's best sketch of c.1646; it is shown clearly in his "Landscape with windmills" of c.1650-52 (particularly on the background mill), and in his c.1650 painting in the Royal Collection.

Only in van Natrus are mill sails drawn; their lead boards are mounted on the ends of the bars (1, plate 9; 2, plate 5-6), but if the leading side weather is different this is not made apparent. However, in 1755 John Smeaton (1724-92) observed the Dutch-built mills at Oostende, and wrote that

> the sails were about 31 feet by 8 broad (9.45 m x 2.4 m); the points of the sails are sprung forward and the leading Boards have a good deal of weather as well at the point above. This I found to be universally the construction all over Holland, & everywhere in the Dutch territory ... (13)

I have no other confirmation of the canted lead board until the design of the standard unbellied mill sail of the Zaan millwright G. Husslage (b.1891), published in 1968 (14). The total trailing side twist is 29.5. There is, very roughly, a constantly accelerating rate of twist from heel to point, so that the outer 40% of the sail has 60% of the twist. The lead board's weather follows the main weather for the inner 33%, and then slowly returns to its heel value, so that at the point the board makes an angle with the sail bar of 150, the bar's weather being -5.33 , and the lead board's +25 . The post-war cloth sails with van Bussel streamlined leading edges on Sluis tower mill (1739) had, in 1965, an unbellied variable weather quite closely resembling this. The sail span was 24 m. The change of weather of the inner one-third of the sail was virtually imperceptible.

The introduction of the canted leading edge may explain the disappearance of the double-sided cloth sail. The overall width of the sail, and the width of the narrow leading side, are unchanged; and as the leading board increases the solid area of the sail some two or three times, its use seems a retrogade step. But once the leading side is canted, the cloth can no longer be spread to lie flat on the sail frame, so a board has to replace it on that side; and see what Burne says below. The canted leading edge is very necessary when the point has a zero or negative weather, so the introduction of the two features may have gone hand-in-hand.

This section should not end without mentining Peter Spier. His eye has captured to a nicety the changing contour of a Dutch mill sail. See his talented and charming pen-and-wash illustrations in his "Of dykes and windmills", New York: Doubleday, 1969.

4) Comments

One of the very earliest serious windmill fieldworkers was the Guildford and London-based mechanical engineer Edward Lancaster Burne, born Croydon district 1869, died 12 June 1946 (15). He had a life-long interest in windmills, which included a specific interest in mill sails. He correctly pointed out that sail design had evolved almost entirely from experience (Smeaton's experimental work probably had no influence), and that knowledge of it was almost entirely confined to the country millwrights. If a sail had a positive point weather, he said in the 1920's, its action was to compress the air between it and the mill body behind it as the sail passed by. This back pressure would cause a flapping of the sail cloth (i.e, towards the point end), which was obviated when a zero or negative weather was used. (I suppose, considered statically, a flat point cuts the air like a knife, and a negative sail point forms behind itself an area of reduced pressure). A zero angle was necessary with shuttered sails, as they would tend to flap too.

But with the "pull" (as the millwright called it) of the canted leading edge, these point angles make little difference to the driving power. The canting, he said, no doubt arose from the necessity of turning the wind on to the cloth in order to prevent sail cloth flutter during the sail's revolution; but millwrights then realised that it increased the torque, and so continued to use it when the shuttered sails came in. The aerodynamic value of this, in terms of the dynamic lift of an aeroplane's wings, was suggested in 1866, and proven by Horatio Phillips (1845-1912) in his design of an aerofoil with a thick, dipped leading edge, the forerunner of modern sub-sonic wing profiles (16).

In 1909, Burne observed (of the leading board):

> Probably the behaviour to the cloth afforded the millwrights a very good guide as to its correct disposition. Be that as it may, recent investigation only tends to prove the soundness of their conclusions (17).

By "recent investigation" he meant the work of the Dane, Poul la Cour (1846-1908), who, in the 1890's experimentally showed the importance of the angled lead board in his wind tunnel testing of modifications of existing mill sails (18). La Cour's work, a refining of existing practice, was commercially proven by several decades of manufacture of sails to his design, the klapsejlere used on the large wind generators of the Lykkegaard Co. As these were patent sails without sail frames to hold the shutters, they were double-sided, with each pair of shutters forming a pivoting beam across the sail arm. The canted leading edge was formed by cranking or bending the outer half of each leading side shutter.

in 1909, Burne also noted that as there is a slight spring or flex in the bars, which in actual work tends to increase the weather angle, the tip bars of cloth sails are sometimes given 2 of negative weather. Possibly, he said this to explain away a negative point weather, which perhaps then puzzled him. He later noted that a sail's centre of pressure is not central, but tends towards the leading side (19).

In the 1920's and 30's, (Johan) Albert Betz (born 25 December 1885 - living 1965), Kurt Bilau and Adriaan J. Dekker of Leyden, developed the leading edge of the conventional mill sail into a thick aerofoil, which tended to be angled forward (or "dipped") in relation to the sail frame. (Burne himself has a niche here. In 1923 he patented a thick, solid double-sided blade for a (small) four-sailed wind engine. The leading edge was streamlined and the whole leading side was canted. It was an empirical modification of windmill practice, and was without issue or influence)(20).

Flanders

I do not know when variable weather sails spread far outside Holland. Today, in French and Belgian Flanders variable weather is universal. In 1755, Smeaton saw near Dunkirk several of the magnificent Flanders post mills. Their sails either had a constant weather of c.18-20 , or were absurdly weathered the wrong way (i.e, the weather was greatest at the point). The span was a clear 88' (27 m), the width c.7.5-8' (2.29-2.44 m). The sails had neither cloth nor lead board on the lead side, and were so raggedly made as to seem "rather the work of an Hedger than a millwright" (21). But around 1780 the distinguished French physicist Charles Augustin de Coulomb (1736-1806) saw on the Lille oil (post) mills, sails of 81' English (24.7 m) span, and 6' 5" (1.95 m) overall width. They had a twist of 18-22 : there was a very large 30 heel weather, which reduced to plus 8-12 at the point. (The point weather he correlated with the slope of the windshaft of from 12 to 6 , an observation otherwise unkown). The lead board was canted at the heel, but not at the point. Its twist was therefore greater than the sail's (22).

Both these meticulous observers thought they had seen mills typical of all of Flanders: but Smeaton journeyed on through the western part of present-day Belgian Flanders, and Coulomb doubtless went to Lille and back from Paris. And though Smeaton passed within 15 miles of Lille, he did not, it seems, see any of its mills; but had he gone there, undoubtedly he would have seen what Coulomb saw 25 years later. It may be presumed that the Lille mill's weather had a Dutch origin, but the form it took was clearly a local development.

Modern Flanders practice (entirely cloth-sailed) seems generally to follow that of the Netherlands, though perhaps with a lesser twist. This is equally true of French or Belgian Flanders, for the political boundary is not a mill one. The French expanded into Flanders (the Spanish Netherlands) under Louis XIV, and the frontier was settled by the Treaty o Utrecht of 1713. The scale of the Flanders post mill was perhaps finalised prior to this, and even subsequent developments of the brick tower mill and in mill sails appear to have ignored it. Rex Wailes's excellent photograph of the 1920's of the splendid post mill at Marke, near Calais, the cloth fully spread on all its four long sails, shows this weather very nicely. It had been reproduced in the Miller, 7 April 1930, p.274, Wailes's Source book of windmills and watermills, London: Ward Lock, 1979, and best of all in the Trans. First International Symposium on Molinology, Lyngby, Denmark: Danske Mollers Venner, and TIMS, 1977, P.111.(23)

England

1) Smeaton, 1750's

Variable weather doubtless came to England from the Netherlands; possibly after 1688, or from mills in the Dutch-engineered drainage schemes. In 1759, Smeaton published the results of his whirling-arm experiments on model mill sails, carried out in c.1751-2 (24). These included tests on three designs of "Plain sails weather'd according to the common practice". They had a constant angle of weather of 12 , 15 and 18 . And tests on "Sails weathered in the Dutch manner". All had 15 twist, measured from the maximum weather 1/3 the radius from the centre, which was only some 3/5 or so of the usage in Holland, and were tested at point weathers varying from 0 to +12 . No point weather was "as they are made according to the common practice in England"; their most common span was 60' (18.3 m). So in the mid-18th century, English mills used both sails with a constant weather, and with a (moderately) variable weather. Smeaton's use of "Dutch" in this context may be vernacular usage, to distinguish them from older, indiginous English mill sails without a twist.

Smeaton also observed that

> The Dutch, and all our modern mill-builders, tho' they make the angle to diminish, in receding from the centre towards the extremity, yet constantly do it in such manner, as that the surface of the sail may be concave towards the wind.

That is, the sails have a gentle bellying as in the English design of "Dutch" sails. From his model trials of the latter sails, Smeaton designed and tested model "Sails weathered in the Dutch manner, but enlarged towards the extremities", with a 15 twist and point weathers varying from +7.5 to +15 . And from these he designed his earliest mill sails. They were double-sided cloth sails, with very wide splayed points. He gave them a heel angle of 18 , a maximum angle of 19 1/5 the way along, and a point angle of +7 (25). This is a twist of only 12 , one half and under of that of Dutch practice.

Smeaton's model experiments therefore influenced his choice of point angle. In 1945, Messrs. Burne, Russell and Wailes observed that:

> If this angle were adopted for a mill with a substantial body the cloth and even the shutters of "spring sails" would flap when passing the body. For this reason the driving side is usually sqaure at the tip and is sometimes even given a negative angle ... in the case of cloth sails (26).

2) Smeaton 1770's

In 1759, Smeaton made no mention of leading edge "pull". It is clear that the concept was unknown to him; that the significance of the Dutch practice he had seen had escaped him, and that his early sails had the same weather on both leading and trailing sides (except that the outer two-thirds of the trailing bars had a gentle concavity towards the wind, of some 30' (9 m) radius, a subtlety that Smeaton himself later discarded, (27). But in 1774 each of his five sails of the Leeds flint mill has a lead board (tapering from point to heel as a vegistial concession to his previous design (28)). The sail has 25 bars. His weathering instructions for it make the weather of bars 1 - 10 a symmetrical bowing or bellying, with the maximum weather at bars 5 and 6; and give the weather a progressive linear reduction to the point bar 25 (clearly, still positive). And he angles the lead board to follow the sail weather of bars 1 - 12, but thereafter to cant progressively in relation to the sail so that at the point the board's angle is the greater by 7.5 . Smeaton admonished the millwright to follow minutely the directions "for the weathering of the sails and boards, the effect depends upon it, and, however uncommon they may appear, the success will follow". He also gave instructions for laying out the mortices with a weathering scale and bevel, essentially the same as Lindberg's. They compare most favourably with the baffling compleity of his early instructions, though these do include how to work out the scale in the first place (29). What was uncommon cannot be the use of variable weather, so it must be its form and the lead board cant. But Smeaton did not have much windmill work. Moreover, many features of his engineering designs remained peculiar to himself. They established no trends and set no precedents.

3) Later practice

A search through older mill photographs has revealed either no leading edge, or (notably in Kent and Sussex), a leading edge flat with the trailing frame at the heel, but canted quite gently at the point. Non-canted lead boards are shown clearly in the photographs of H.E.S.Simmons (1901 - 26 October 1973), on the cloth sails of the quite small Sufffolk drainage tower mills with scoop wheels and tailpoles, at Belton Marsh (1938) and Walberswick (1934). Leading edges angled at the point are shown clearly in the whole page photographs of Bexhill-on-Sea, Argos Hill, Cross-in-Hand and St. Leonard's Silverhill in Peter Hemming, Windmills in Sussex (1936). Mr Simmons shows a gentle leading edge point cant in most of his excellent 1930's photographs of Lincolnshire mills with double-sided patents, notably Kirton in Lindsey, New Bolingbroke and Epworth (all 1934), but on the double-sided sails of Suffolk his photographs show that this was not the case.

The fieldworkers of the 20th century in England and Wales have met with varialbe weather only. but it varied almost an a county-to-county basis, and can be slight (giving a sail rather flat to the wind), or pronounced. On Kent and Sussexx mills it was slight or fairly slight; in Essex it was pronounced. Only in Anglesey was a negative tip weather recorded; by Rex Wailes (1901 - 7 January 1986), at Llynan tower mill, Llandeusant, in the 1930's. Span 69' 6" (21.2 m). The cloth sail tapers from 7' 9" (2.36 m) to 6' 3" (1.91 m) at the point. Heel weather 20 , tip weather -5 , no bellying, uncanted lead board throughout (30).

I think that in most counties the change of weather tends to be fairly uniform along the sail, giving a "flat twist". The last working sails on Upminster smock mill, Essex, show this clearly. They are double-sided patents (with no cant on the leading side), and have a pretty contant change of weather from 23 to almost zero (31). But in contrast, Lincolnshire mills have a dramatic non-linear twist, requiring a curved or bowed hemlath to follow the line of the bars. A careful examination of Mr Simmons's photographs suggests that the bow is the flattening out towards the point of a sail frame which had kept its maximum weather from the heel to the sail's mid-point or beyond. Only in one or two cases, e.g, Keys Toft tower mill (1935), can a just pereptible bellying towards the mid-point be detected (32).

Notes

1. Simon Stevin, Principal works, v, ed. R.J.Forbes, Amsterdam, 1966, p314; Gerard Doorman, Patents for inventions in the Netherlands ..., The Hague, 1942, p170. Cassell's Dutch dictionary defines "zeeg" as sheer in the nautical sense of to deviate from course.
2. Simon Stevin, op. cit, v, pp314, 319, plate opp. p333. It is a drainage engineer's severely practical design for a large, developed wind engine.
3. "Landsccape with mills", 1607, Rome, Palazzo Spada, inv. no.138 (Klaus Ertz, Jan Brueghel der Ältere (1568 - 1625):die Gemälde mit kritischem Oeuvrekatalog, Köln, 1979, p65, fig.26), right hand sail. This is the sole one of Brueghel's mills where artistic license in the sails is subordinated to reality.
4. David Freedburg, Dutch landscape prints of the seventeenth century, British Museum publications Ltd, 1980, plate 30.
5. Seymour Slive and H.R.Hoetink, Jacob van Ruisdael, NY: Abbeville press, 1981, plates 58-60.

6. Cleveland Museum of Art, reproduced (very small), ibid, fig.17
7. Ibid, plate 10.
8. The original measures c.500 mm x c.375 mm inside the frame. It is now so dark that more can be seen in the Gallery's postcard of it, but this has trimmed the top sail, which in the original appears for three-quarters of its full length, hence much of the apparent tapering of it as it flattens out is lost. Kalraet has bludered in stopping the tailpole at the ladder. (Both Dulwich paintings are reproduced in the Picture Gallery's illustrated catalogue).
9. (Pehr Lindberg), Architecture mechanica. Moole boek of eenige opstalle van moolens nessens haare gronden etc: getekend door Pieter Linpergh (sic), moolemaker van Stocholm, nieulyke in plaat-druk uytgegeeven dor Iustus Danckerts. Amsterdam: Iustus Dankerts, 32 folio plates, n.d.
10. Pieter Linperch, Architectura mechanica, of moole-boek ..., Amsterdam: Johannes Covens & Cornelis Mortier, 1727. The final corruption of Lindberg's name.
11. Jacob Leupold, Theatrum machinarum generale. Schau-platz des Grundes mechanischer Wissenschaften: Leipzig, 1724, p.128. This is a translation of Lindberg's text, but my measurements are off Lindberg's plate 11.
12. Leendert van Natrus, Jacob Polly and Cornelis van Vuuren, Groot volkomen Moolenboek: engraved by Jan Punt, i an ii, Amterdam: Johannes Covens & Cornelis Mortier, 1734, 1736, each vol. 27 plates; Johannes van Zyl, Theatrum machinarum universale; of groot algemeen Moolen-boek: engraved by Jan Schenk, i, Amsterdam: Petrus Schenk, 1734, 56 plus 6 plates. Re-issed Amsterdam: Petrus Schenk, 1761.
13. Diary ..., 1755 (1938), p.12. Smeaton and Lindberg must be the two best informed foreigners to have examined the Dutch windmill in its heyday.
14. G.Huslage, Windmolens: 2nd ed, Amsterdam, 1968, p.126 (1st ed. is Amsterdam, 1965.
15. A good obituary in Engineering, clxi, 21 June 1946, p.592.
16. E. Lancaster Burne, "Wind power", Engineer, cvii, 19 March 1909, pp.286-7; Trans. Newcomen Soc, iii (1922-23), p.49; Oliver G. Sutton, The science of flight, Penguin, 1949, p.81.
17. Engineer, 19 March 1909, p.287.
18. Felix von König, Windenergie in praktischer Nutzung, 3rd ed, München: Udo Pfriemer Verlag, 1981, pp.120-124.
19. Burne (1909) and (1922-3). Burne (1909) said that most mill bodies were fairly substantial, so a zero point weather was needed, but when they were slender, the tips of shuttered sails usually had an angle of +7 . And he said (1909) that windmills were evidently designed to reach their normal speed in a 12-14 m.p.h. breeze (5.4 - 6.3 m/sec, Beaufort 4, thin branches sway), and that 20 m.p.h. (9 m/sec, Beaufort 5, small trees sway, dust) may be generally considered as the useful limit. The wind/tip speed ratio is around 1:2 to 1:2.5 (Smeaton in 1759 gave it as 1:2.6 to 2.7). The sail area of an ordinary narrow four-sailer is c.25% of the swept circle.
20. No. 194 805, application date 20 Dec. 1921, complete specification left 1 July 1922, accepted 20 March 1923. One of the designs shown folds back either side of the sail arm as in his patent no. 165 542 of 1921.
21. Smeaton, op.cit, pp.3-4.
22. Charles Augustin de Coulomb, "Observations theoriques et experimentales sur l'effet des moulins a vent, et sur la figure de leurs ailes", Histoire (with the Memoires) de l'Academie Royale des Sciences, for 1781, Paris, 1784, pp65-81 of the Memoires. Read 22 December 1781. The sail description is on pp.68-9. (Precis in the Histoire, pp.41-4). The hemlath had a gentle concave bow (i.e, to follow the weather). The description is Coulomb's best generalisation from what he saw, for the millwrights had a fixed weathering rule, though they though it the mystery of their trade. Plus ca change ... The Netherlands alone seem to be the exception to this myth of the mystery of mill sail sail making.

23. In the Miller, Wailes said the mill was built in 1769, was turning at 20 r.p.m, and driving two pairs of 572" (1575 mm) stones). I once heard Mr Wailes say that the miller stopped the mill for him to photograph it.
24. John Smeaton, "On the construction and effects of windmill sails", Phil. trans. of the Royal Soc, li/l for 1759, London, 1760, pp.144, 147-8, 168, and plate.
25. Abraham Rees, Cyclopaedia (1819), art. "Wind-mill", by (John Farey jr.), rules for modelling the sails of windmills, by (Smeaton), rule 14.
26. Trans. Newcomen Soc, xxiv (1943-45), pp.149-50.
27. Smeaton's Designs, Royal Society, i, f.3.
28. John Smeaton, Reports, ll (1837), pp.120-21; Denis Smith, in Alec W. Skempton (ed.), John Smeaton, FRS, London: Thomas Telford, 1981, p.78; Rex Wailes, in Trans Newcomen Soc, xxviii (1951-53), plate 34.
29. Rees, loc. cit.
30. Rex Wailes, in Inventory of the ancient monuments of Anglesey, HMSO, 1937, p.clxv, and plate 126.
31. Kenneth G. Farries, Essex windmills ..., London: Skilton, 1982, p.59.
32. The dramatic effect of a Lincolnshire weather I saw clearly in 1960 on the sail frames that Mr Thompson, of Alford, Lincs, had then just erected on Kingsdown smock mill, Kent. They were his signature on any Home Counties windmill he worked on.

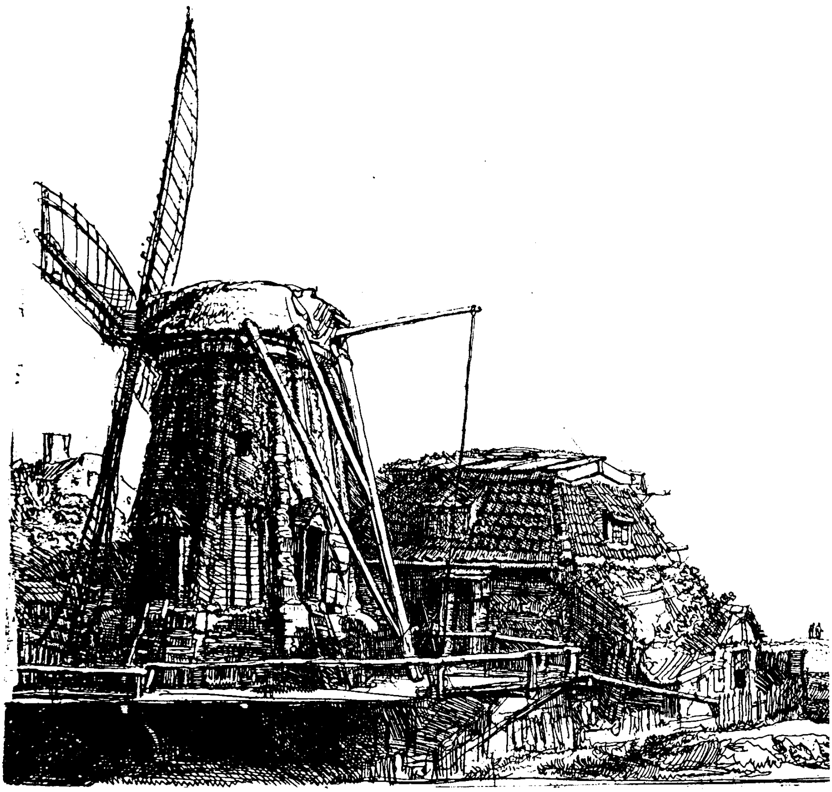


Fig 1.
Rembrandt, "The Mill", 1641.

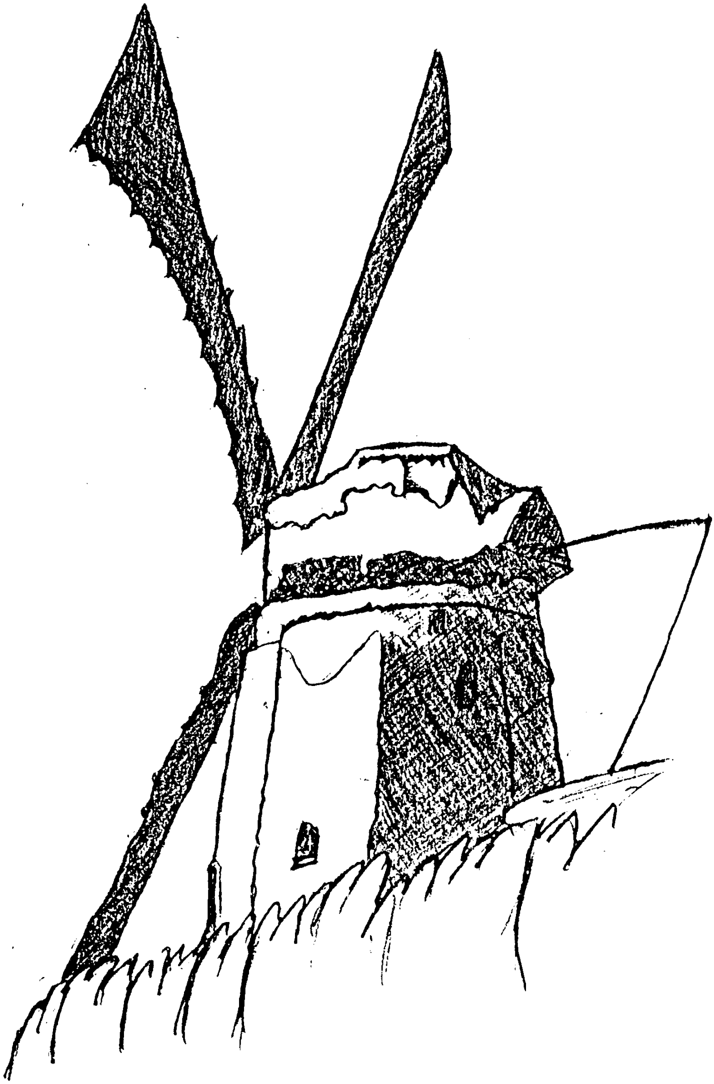


Fig 2.
After Jacob van Ruisdael, "Landscape with Windmills", (near Haarlem), c.1650-52. (Dulwich Picture Gallery).

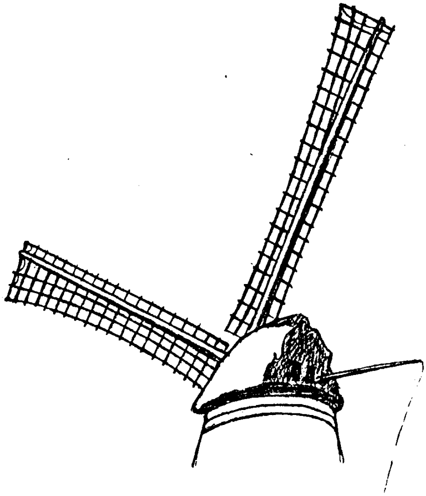


Fig 3.
After Jacob van Ruisdael, "Landscape with Windmills",
(near Haarlem), c.1650-52. (Dulwich Picture Gallery).

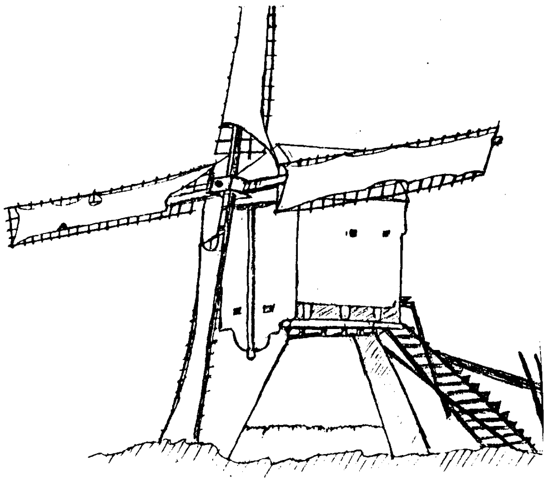
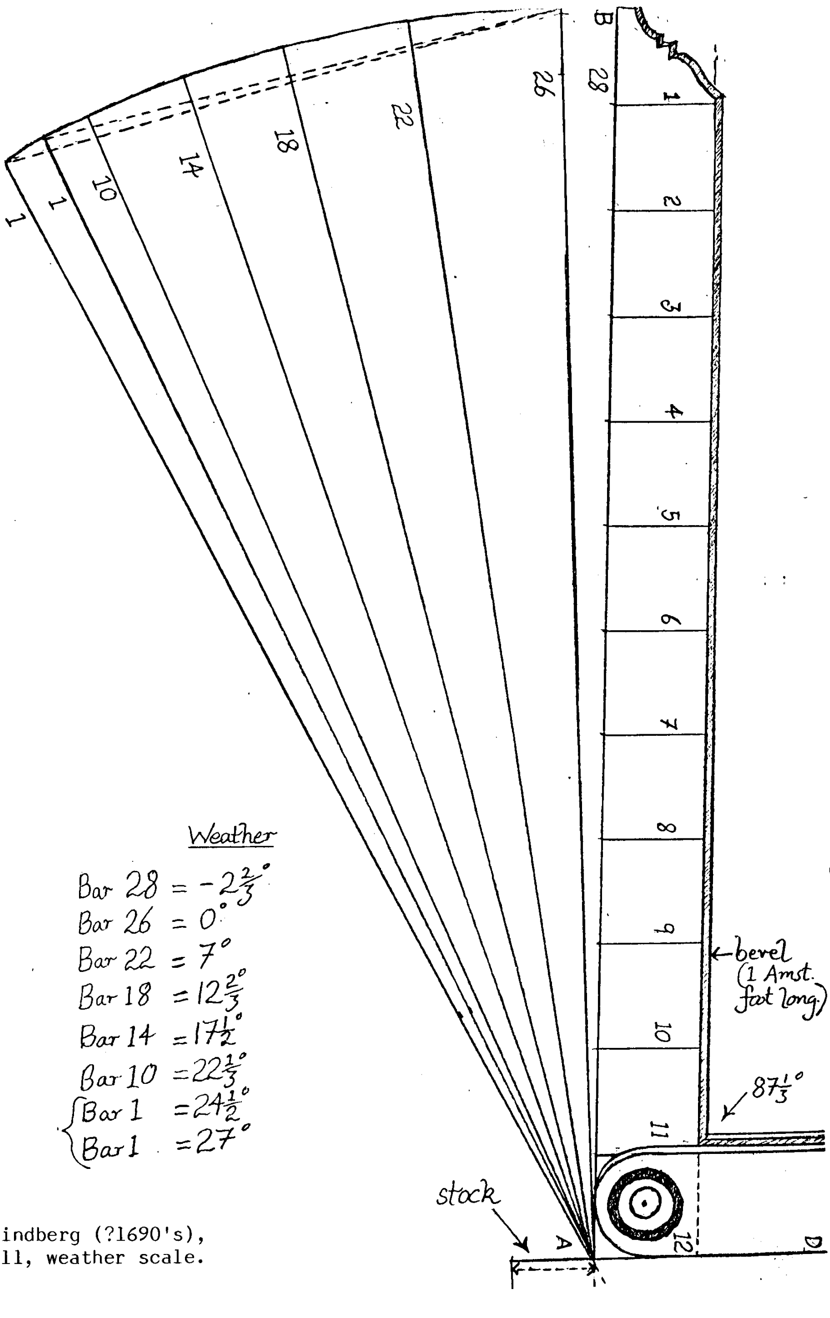


Fig 4.
After Abraham van Kalraet (1642-1722),
"Fishing on Ice", (Dulwich Picture Gallery).



Pehr Lindberg (?1690's), plate 11, weather scale.

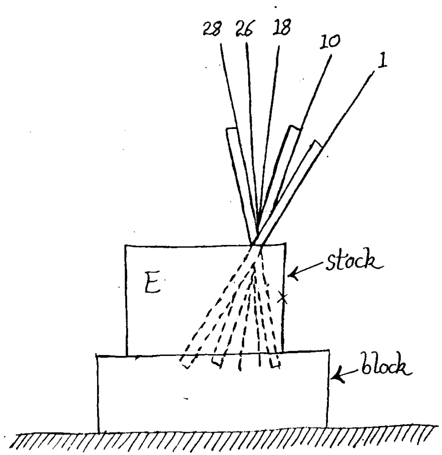


Fig 6: Pehr Lindberg (?1690's), plate 11, mortice angles.

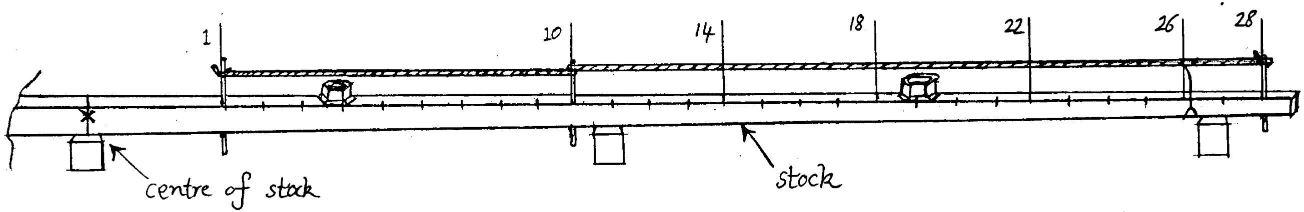


Fig 7: Pehr Lindberg (?1690's), plate 11, (figures with augers omitted). Laying out mortices.