Windpower in Eastern Crete

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Published by:
The Newcomen Society
The Science Museum
South Kensington
London SW7
United Kingdom

Paper copies are 0.35 British pounds.

Available from:
The Society for the Protection
of Ancient Buildings
58 Great Ormond Street
London WC1, England

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Excerpt Transactions of the Newcomen Society
Vol. XLIV, 1971-1972

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That Crete was a land of windmills was one of the many useful things which the author had learnt from his daughter. As an undergraduate student of the classics she had noticed and photographed the massed windmills of Malia when visiting the Minoan site.

The Aegean windmills, in common with those of north western Europe could, in modern terminology, be classed as full-admission axial-flow machines. Here the similarity ends so far as the wind-wheel is concerned. Forbes[1] suggests that the Aegean may be a later adaptation of the western tower mills. The western mills evolved through the post to the tower stage and the post mill has never been recorded in the Aegean. There are indeed tower mills on the coast of Crete near to Spialonga but the majority of (mostly ruined) corn mills sighted by the author in Crete were not on the coast but on the mountain ridges and they were described as "monokairos," that is they were permomently pointed in one direction. Their concept could be even more primitive than either tower or post since it contains no element of direction seeking (Plate XXXII (*a*) and (*b*)).

The aerodynamic characteristic of the Aegean mills is in their use of a fairly large number (six to twelve) of canvas sails rigged so that their shape can comply with the forces acting on them. Indeed, the mill incorporates aerodynamic and structural features of the modern racing yacht; that is, it is a fully triangulated structure of spar and stay flying triangular sails. These sails, which are capable of roller reefing, are sheeted amidships and the mill sails forever with the wind on the beam.

As a structure, it can hardly be improved for the efficient use of material. Aerodynamically, the low speed efficiency is high and it has an inherent stability against accidental overspeed. Overspeed is analagous to sailing too close to the wind with the inevitable consequence of the sail being taken aback and an automatic loss of propulsive force. The finely pitched aerofoil, on the other hand (in a windmill context), has an inbuilt urge to self destruction should the restraining load be accidentally removed, a property analogous to that possessed by a D.C. series-wound electric motor.

The machines seen in Crete were small by west European standards. The range of size was from 4 m. in diameter for the smaller irrigation pumps to 12 m. in diameter for the corn mills (compared with 29 m. diameter for a large Dutch polder mill). This size limitation is by no means inherent in the construction. The concept of optimum size seems to have been instinctively appreciated in the Aegean. The power of a given type of windwheel must depend on the area it presents to the wind. That is, on the square of the linear dimension. The weight (and cost) of the material depends on the cube. To double the size of a windwheel is to quadruple its power and to multiply its use of material by a factor of eight.

It might well be better to build four little windmills than one big one. Twelve or more (mostly ruined) corn mills can often be seen in a row along a mountain ridge in Eastern Crete and in any one irrigation area the number of machines may be measured in hundreds or even in thousands. The survival of windpower in Crete, so long after its decline elsewhere, must in part be attributed to intrinsic excellence of the local machines as well as to local circumstances.

[1] Forbes, R. J. in *History of Technology*, II (1956), 618.

The Aegean Windwheel

The Aegean windwheel (Fig. 1 and Plate XXX) has an even number (six to twelve) of radial arms or spokes.[1a] From the hub of the wheel there is an upstream extension of the windshaft which may well be called a bowsprit. Forestays extend from the tip of the bowsprit to the outer ends of the arms. Again these arms are stayed to each other in the plane of the wheel. By a rather severe stretching of the nautical analogy these tip connections could be called the triatic stays. Each radial arm flies a trisail sheeted to the adjacent triatic stay or to the arm behind.

The windpump wheels invariably utilise an iron windshaft with some form of hub, hence the spokes or arms are all in one plane (or occasionally the arms may slope slightly, about 5°, and thus lie in a conical surface).

The corn mills however, use a massive wooden windshaft and no hub. Pairs of arms are mortised into this shaft. No two pairs can lie in the same plane for this would involve undue localised weakening of the shaft. The arms are displaced axially at the hub but at the tip they are strained to lie in the same plane. In this respect the Aegean mills seems to differ from illustrations which the author has seen of some mills in Portugal. The Aegean mill has a capacity for sail change equivalent to that of a sailing ship and can utilise almost as big a range of wind speeds. Each individual sail can be reefed until the bare pole condition is reached. No corn mills were observed at work but, in the case of the windpumps, sail appears to be set appropriate to a speed of 25 revolutions/min. or less. The sails in use are generally (but not invariably) symmetrically distributed around the periphery (Plate XXXII (*c*) and (*d*)).

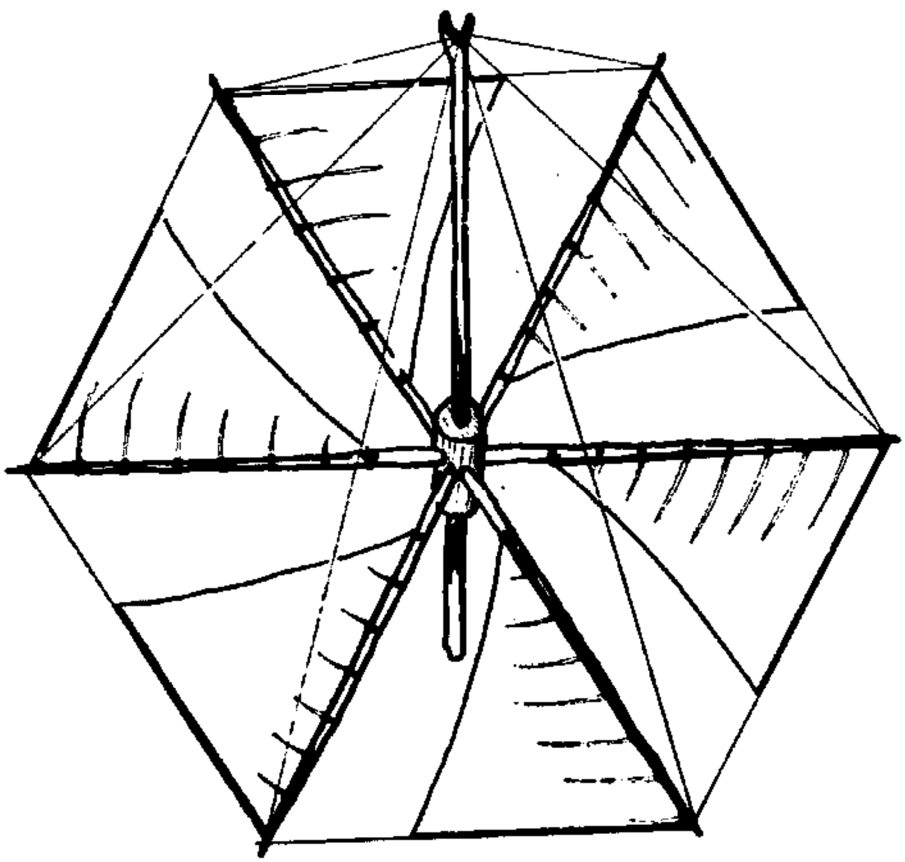

Fig. 1. Typical Aegean Windwheel

[1a] *Ibid.*

Irrigation Mills in Eastern Crete

The largest concentration of irrigation mills in Eastern Crete is in the mountain plateau of Lassithi. The number there is variously quoted in current guide books and tourist brochures as six, ten, twelve or fifteen thousand. Whatever the figure may be it is impressively large. The next largest group is probably that on the coastal plain in the neighbourhood of Malia. Other, much smaller groups of irrigation mills have also been visited at Limnes, Agios Nikolaos, Pachia-Amos, Sitia and Palaikastro.

Characteristically, each wind pump is mounted over a stone-lined well some six or seven metres deep and about two metres in diameter. The pump discharges into a stone built, cement lined cistern of about eight cubic metres capacity. The cistern is built above ground so that the adjacent garden has a gravitational supply. The fact that each garden plot may have its own well, wind pump and cistern means that groups of mills are often found very close together. The great bulk of the irrigation mills are less than fifty years old. A superficial view from a little distance suggests that the Cretan wind pumps are very much alike. Closer examination reveals almost indefinite variety of constructional detail.

The first step towards the understanding of a complex situation is classification. The author suggests the following, based on the skills and resources used in construction:

(*a*) Those which could have been built by a blacksmith-wheelwright. These use both wood and metal in construction and employ the wedge and the rivet for fastening.

(*b*) Those which could have been built by the ingenious mechanic of the fifth decade of this century. These use little if any timber and employ metal parts gas-welded or bolted together. These parts may suggest automotive origin and the salvage of military debris. The two types (*a*) and (*b*) could correspond respectively to periods of reconstruction following the years of 1914 and 1939.

(*c*) A very few which are characterised by a stone tower instead of one of lattice steel construction.

There are also hybrids of the above.

A machine of type (*a*) is shown diagrammatically in Fig. 2. The tower is constructed of angle iron surmounted by a "kerb" of similar material neatly bent into a circle. The windshaft, inclined at 15° to the horizontal, is of square section bar. On this, a central crank, formed by bending, gives the necessary reciprocating motion to the pump. The bearing surfaces both for the shaft and the crank pin suggest work on the forge rather than on the lathe. The necessarily split bearings are of wood and the bowsprit is of angle iron split and bent into a double claw at its outer end. The hub of the windwheel is a cylinder of wood, protected from splitting by irons bands, and mortised to receive the windwheel arms. The arms, themselves normally eight in number, (exceptionally six or ten) are of riven wood. The stays are either of fencing wire or of chain. Axial thrust may be transmitted from the hub to the adjacent bearing by a wooden distance piece threaded over the shaft. Sometimes provision for axial thrust is not apparent from ground level. A greasy lubricant appears to be used, but there is never any sign of paint or preservative. The wooden tailpole carries a triangular wind vane from which dangles a cord or chain for manual control.

The pump barrel is often of copper, open at the top, delivery being by a spout at one side. Bore and stroke are each about 0·125 m. (nearly 5 in.). No brake of any form has been observed. There is no unnecessary refinement of construction.

Type (*b*) mills are of similar appearance but practically every detail differs from type (*a*).

Type (*c*). At Malia, Agios Nikolaos and Limnes a minority of the mills are mounted on a tower of stone instead of angle iron. This did not so much indicate greater age as greater ingenuity on the part of the builder seeking to avoid the high cost of angle iron. One such stone tower at Malia had

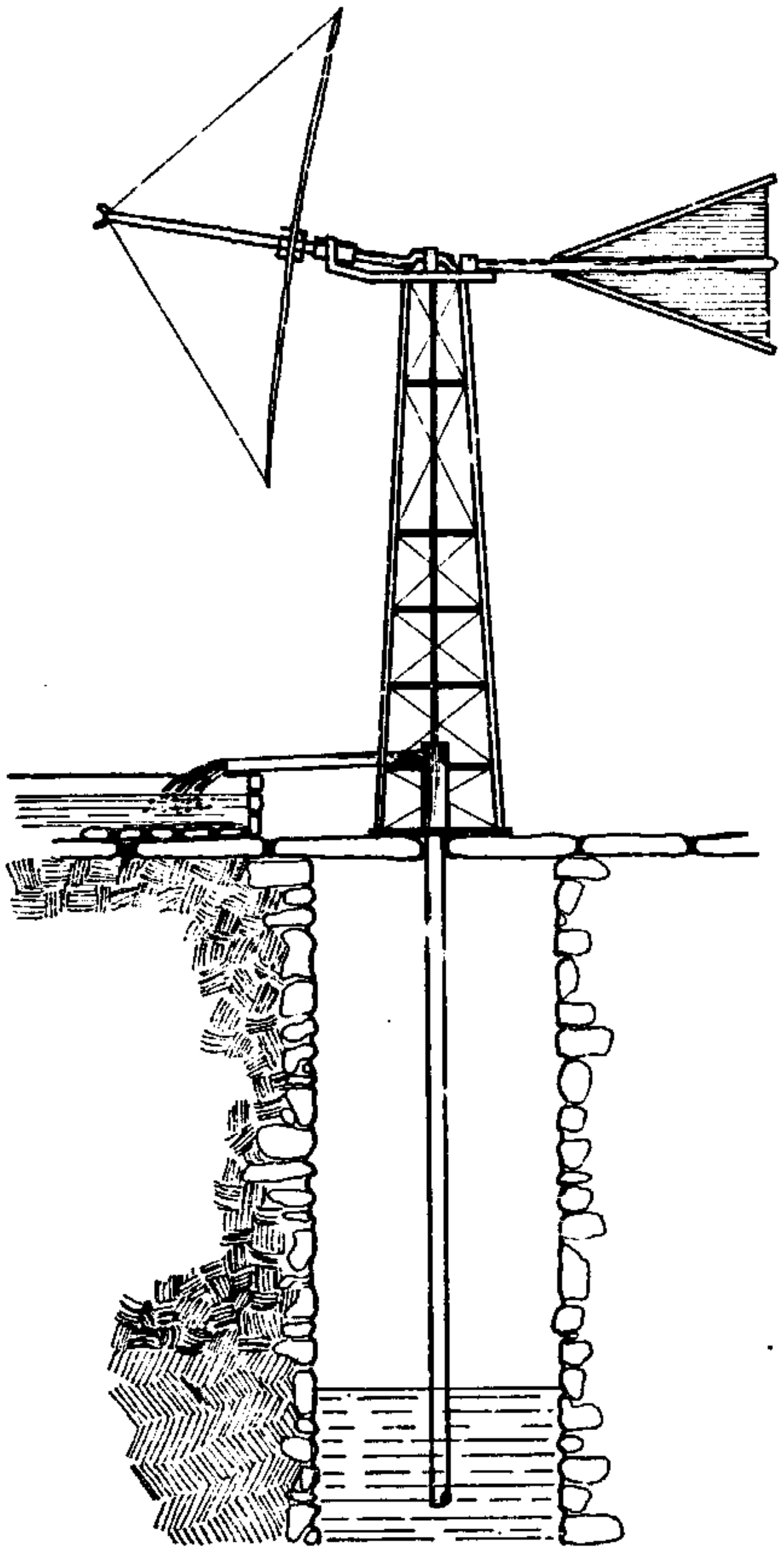

Fig. 2. Irrigation Wheel on Metal Tower

the date 1951 scratched in the cement rendering over the doorway. This was unusual in that it was not built directly over its well; there was a short horizontal run of suction pipe. The stone towers were hollow to take the pump rods, and each had a small doorway (too small for a man to enter) to give access to the pump. Steps are arranged on the outside of such towers to give access to the sails. These may take the form of either projecting stones or of foot holes left in the structure. Distribution in either case is helical so that the climber winds around the tower as he ascends.

Two stone-towered irrigation-mills were observed at Limnes which could have been much older (Fig. 3). These had a wooden curb and wooden superstructure. Unusually they had ten arms and horizontal windshafts. They had a tailpole but no vane. Limnes is in a mountain valley and on the adjacent ridges are rows of (unserviceable) monokairos corn mills. These corn mills were reported in use in 1930.

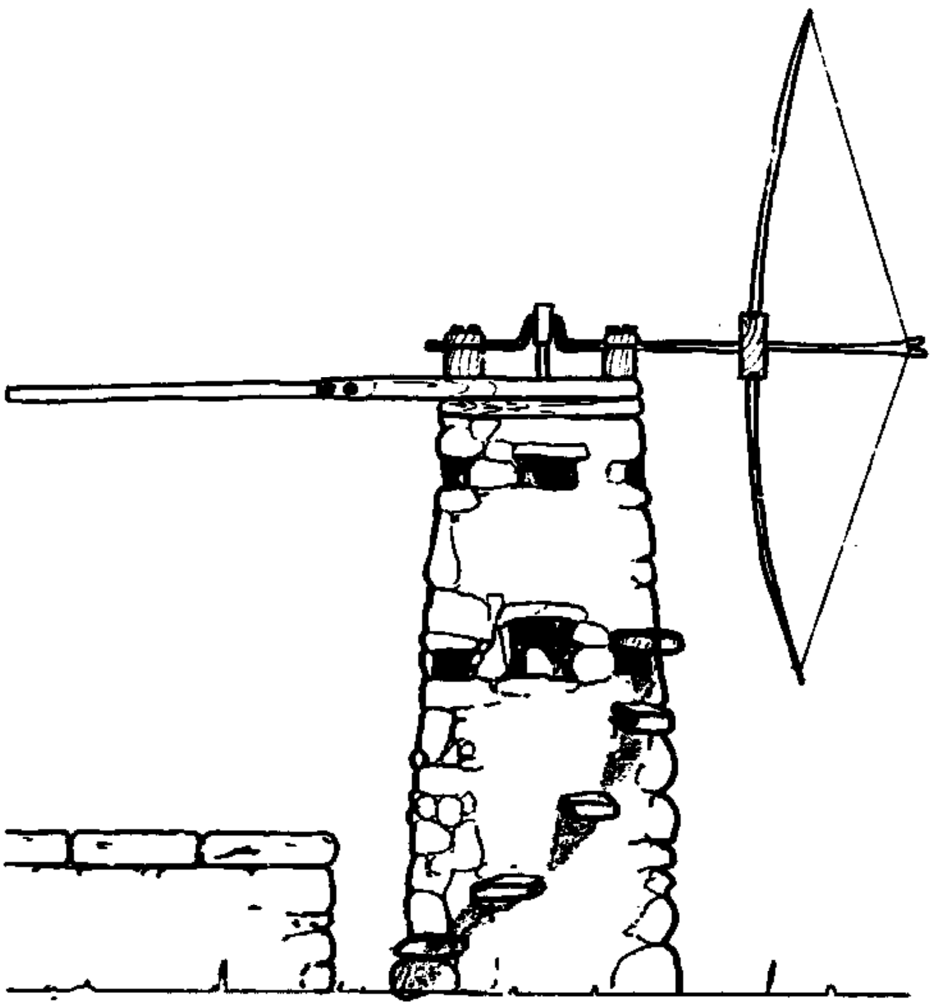

Fig. 3. Irrigation Wheel or Stone Tower

At Agios Nikolaos several stone (irrigation) mill towers survive without superstructure in suburban gardens and shop forecourts. Some of these, along with a stone platform for sail changing, are in finely built Ashlar masonry.

The pumps in the older towers are commonly ordinary cast-iron well-head lift-pumps with the handles removed and the connecting rod attached.

The Performance of the Cretan Wind Pump

The author's visit to Crete was early in the irrigation season and only a few machines were seen at work. Opportunities for measurement in the field were limited to wind speed and rotational speed. Observations were made on a number of machines, in the fully rigged state and in rotation, at wind speeds commencing at 2·2 metres/sec. (5 miles/hour). A useful output of water appeared at a wind speed of 2·75 metres/sec. (6 miles/hour). When the wind speed rose to 3·5 metres/sec. (8 miles/hour) a four-metre diameter machine would run at a speed of up to 25 rev./min. No rotational speeds higher than this have been observed. Higher wind speeds were in the author's experience associated with reduced sail.

Corresponding figures for a Northern Mill are available. F. Stokhuyzen[1] gives 5 metres/sec. as the wind speed at which a Dutch Polder Mill begins to rotate, and 8 metres/sec. as the wind speed which brings it up to full power. The comparison is interesting but it does not of itself imply superiority of one type over another. The draining of a Polder during a Northern winter is a very different duty from irrigating vegetable crops during an Aegean summer.

Since the author had no facilities for power measurement in Crete, an aerodynamically-similar machine has been built and tested in Britain. Tests on the British machine suggest that a four-metre diameter wind-wheel of the Cretan type, when full sail is set in a wind speed of 3·5 metres/sec. (8 miles/hour), can develop a power of 220 watts. Since the test machine incorporated refinements, such as ball bearings and terylene sails, its performance can be expected to be higher than that normally experienced in the field. Even so, there is no doubt that the Cretan Mill excels in its ability to utilise low wind-speeds. This is consistent with the maximum number of operating hours per year and, in an irrigation context, is probably a criterion of excellence.

Efficiency in an aerodynamic sense can be defined as the ratio of the power developed on the windmill shaft to that of the wind which passes through the disk of rotation of the wheel. At low powers, efficiency may have little significance for, since the wind is free, and there is no size restriction, low efficiency can, (up to a point) be compensated by increased size. Even so, it is interesting to note that the efficiency of 0·3 measured in the author's tests compares satisfactorily with that recorded for any other type of windmill, except for model machines made with aerodynamically precise surfaces.

Beginning of Decline

Decline in the use of windpumps is apparent on the coastal plain where more of them appear to be in ruin than in use. A similar decline is reported, but is not yet so obvious, on the mountain plateau of Lasithi. In an intensive system of agriculture aimed at an export market dependence upon the uncertainties of the wind becomes less acceptable once other means of pumping are at hand. Electricity is now widely available and donkeys, with petrol driven pumping sets on their backs, plod through the Malia gardens.

As the mills fall in ruin, some are being re-erected as forecourt features in the new hotels and in suburban gardens—much as wooden cart wheels are used in Britain. Indeed, in one case a representation of a Cretan windpump has been re-built as a screen for the kitchen ventilator of a beach hotel.

A different factor may have been dominant in the decay of the windpumps at Agios Nikolaos where only one Cretan mill appeared to be serviceable. When the gardens were formed olive bushes were planted around them. Now that the olive trees are of mature size, the mills are screened from much of the wind. There were, however, several American mills that towered high above the trees and worked steadily. Otherwise, pumping has been taken over by the petrol engine, but the shadouf (locally "yerani") is still in use.

[1] Stokhuyzen, F., *The Dutch Windmill*, London, 1962.

Cretan Mills in English Language Publications

Crete has been well served by English-speaking travellers; many have written books on their experiences, but most had a blind spot as regards windpower. Whether it was so rare as to escape notice, or too common to comment on, is not at once apparent.

Pashley,[1] whose travels began in 1834, sought mainly for archaeological sites which could be identified in the classical texts. He recorded much folklore and made occasional reference to aqueducts and water mills. Once only, and that in a footnote, has the author found references to a windmill (presumably a corn mill, in the extreme north-west).

Captain Spratt[2] (1865) of the Mediterranean survey travelled widely and climbed mountains on his journeys of triangulation. He too had a keen eye for antiquity; he noted every wartermill he saw; but never once did he mention any kind of windmill. In writing of the mountain plateau of Lasithi he mentioned the drainage dikes but did not record any instance of wind-pumped irrigation.

Battye[3] who travelled through Crete in 1913 was interested in Natural History. He noted the unloading of a millstone from a coastal steamer and took delight in watermills, but never once did he mention a windmill. However, his book is illustrated with photographs and on one, featuring a threshing floor, there are four unmistakeable irrigation windpumps. There is no clue as to where it was. These machines, although rather out of focus, can be seen to be of timber construction and apparently without tail vanes. They have eight arms. This is as far back as the author has been able to trace evidence of the irrigation mill.

Dorothea Bate, who published with Battye in 1913, described the view of the Plateau of Lasithi as seen from the mouth of the Dictean Cave "spread out like a map below" . . . "a vast and irregular chess board." She never once mentioned a windpump, although today these are the dominant feature of the view.

Holdt[4] (1928) included a picture "Mount Dikte with Windmill." This is a view across the plateau with a single windpump in the foreground and three or four faintly identifiable in the background. The mountain features show that this view point is the same as that used in current picture postcards of "The Plateau of ten thousand windmills."

Elliadi[5] (1933), on his journey from the former Imperial Airways base at Spinalonga to Heraklion, recorded the row of windmills at work near Neapolis. These must be some of the rows of now-ruined corn-mills along the mountain ridge, for the windpumps in the valley bottom are not in a row but have a random grouping.

In the late 1930s geography text-books began to refer to "irrigation dependent on numerous windmills" on Lasithi.

Currently, in 1972 when they are in decline, windmills feature in all the relevant tourist brochures.

Acknowledgements

The Author wishes to thank Mr. J. Woollam for the preparation of the diagrams, and gratefully to acknowledge the help he received from the British School of Archaeology in Athens.

[1] Pashley, R., *Travels in Crete*, John Murray, London, 1837.
[2] Spratt, T. A. B., *Travels and Researches in Crete*, London, 1865.
[3] Battye, A. T., *Camping in Crete*, London, 1913.
[4] Holdt, *Greece*, London, 1928.
[5] Elliadi, M. H., *Crete, Past and Present*, Heath Cronten, London, 1933.

APPENDIX

The following are the Author's isolated observations; they are not put forward as giving a complete picture of Cretan Windpower in 1972.

Three corn mills of the monokairos type (apparently intact and in working order) were observed at Eko-Laconia, and one at the Monastery of Topli.

One complete and rigged tower mill was seen East of Sitia and another at Pines, near Elounda. In the latter case the author had (through an interpreter) a conversation with the miller. The following points were noted. The tower mill stood among a group of five derelict monokairos mills. One of these was said to be two hundred years old. The others were more recent; one bore the date 1884. The tower mill was said to have been built subsequent to 1939 on the site of a mule-mill. The tower mill had twelve arms, 6 metres long, and a horizontal windshaft. The windshaft centre height was seven metres.

The gear ratio of toothed wheels, both in the tower mill and in several of the ruined monokairos mills, was 40:8. No evidence of any type of brake was found. The wheel at rest would be spragged to the ground by forked branches. The output of meal (type not specified) was reported to be between 20 and 700 kg. per day according to the wind. The miller retained 10 per cent.