

FOOD FROM WINDMILLS

A report on the wind mill irrigation
project initiated by the American
Presbyterian Mission at
Omo Station in Ethiopia

by

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1. INTRODUCTION

This report describes work done to improve and evaluate a series of wind-mills developed for irrigating small plots of land on the banks of the Omo River, using river water. The systems were developed by the American Mission for use by the local people in order to permit all the year round cultivation which is not otherwise possible. At the time of the author's visit (July-August 1975) some 19 windmills of various types were operational and under the control of local villagers and a further five were in operational condition on mission land for cultivation, experimentation or demonstration. Eleven further sail wind-mills had been completed and awaited installation for villagers requiring them.

The American Mission had applied to OXFAM for funding to allow the construction of further wind-mills. A condition of the grant was that an engineer should visit the project in order to evaluate, advise and report.

Objectives

- (i) to seek methods of improving the general design and performance
- (ii) to evaluate the performance of the machines
- (iii) to advise on the collection of meteorological data and to make a preliminary assessment of the suitability of the wind régime
- (iv) to provide a detailed report describing the project and to suggest circumstances under which this type of system might be used in other situations
- (v) to make recommendations for further development work.

Acknowledgements

I should like to acknowledge with gratitude the

assistance given by numerous people with this project, and in particular the kindness and hospitality received throughout my travels in Ethiopia. Particular thanks are due to the American Mission, especially the Rev. and Mrs. J R Swart who conceived this project and were very kind hosts during my stay at Omo Station, and to Mr. E O Pollock the inventor of the original Polomo mills and the source of much inspiration. Special thanks are also due to Mr. P H Stern, ITDG Water Consultant in Ethiopia, who proposed and arranged my visit and who gave valuable technical support, and to Mrs. Stern for their kind hospitality in Addis Ababa. Thanks are also due to OXFAM who financed the field work needed to prepare this report and to ITDG who contributed financially and made many of the necessary organisational arrangements.

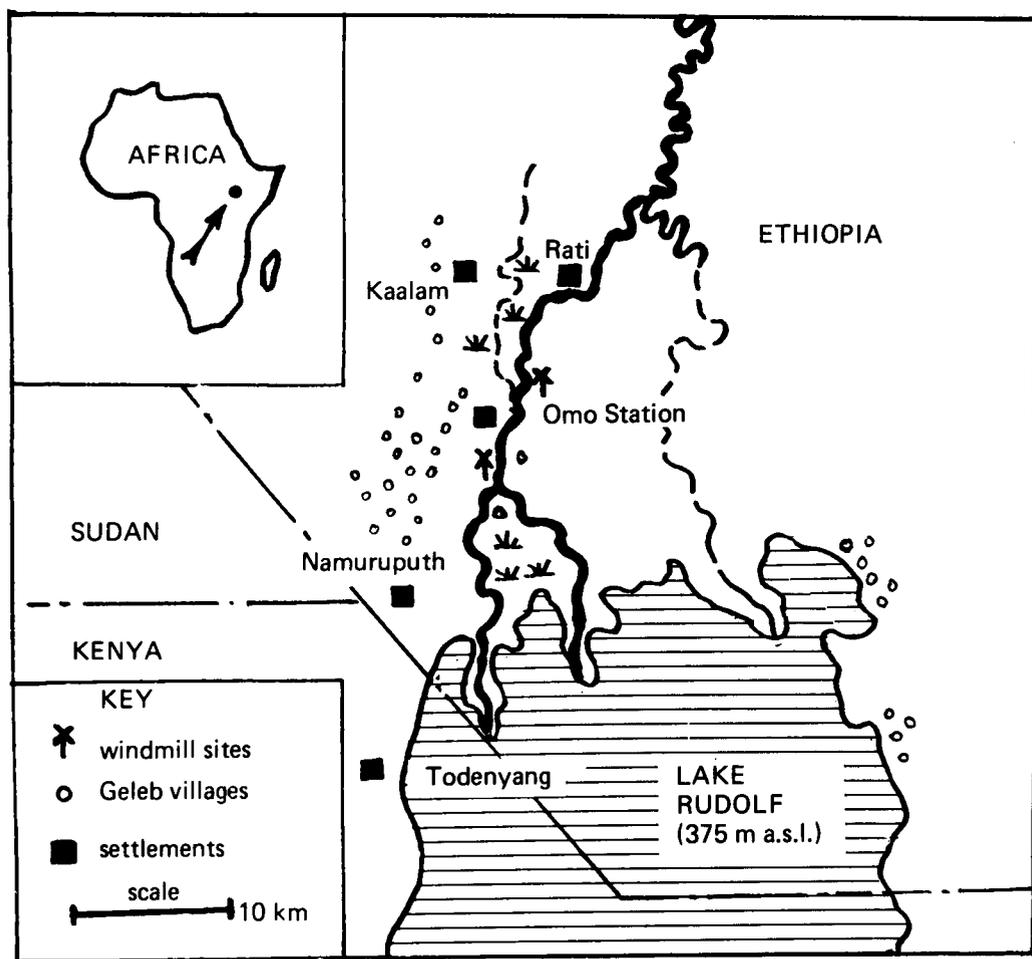
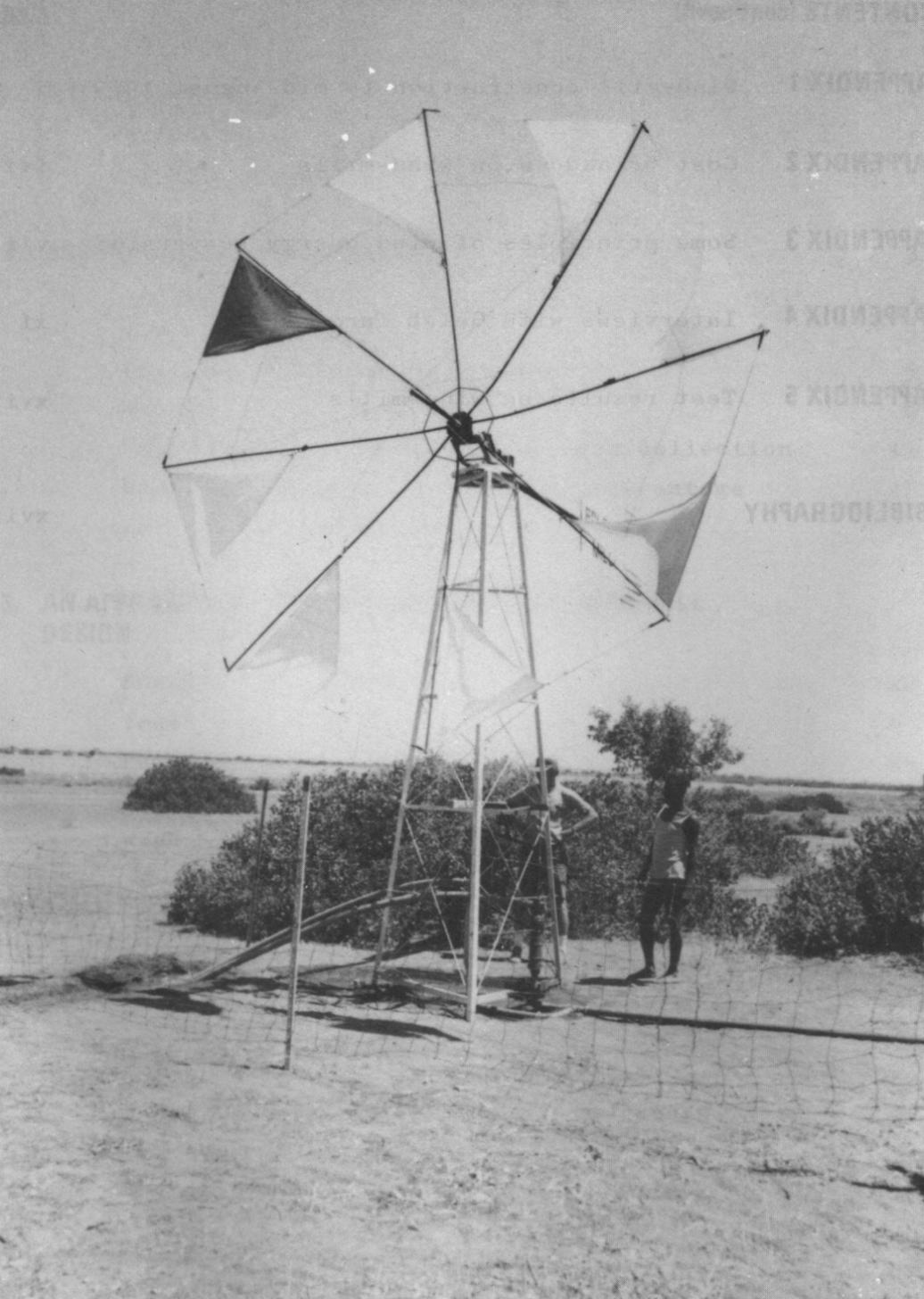


Fig 2.

fig 1.

Modified 16 ft diameter Cretan sail windmill. The inner concentric ring of bracing wire indicates the original wind-wheel diameter of 11ft. This experimental unit was also fitted with two opposed single-acting pumps and an interim extended tail vane.



2. BACKGROUND TO THE PROJECT

Location

The Omo mission station is about 10km north of Lake Rudolf in the extreme south-west corner of Ethiopia, in Gemu-Gofa province, situated on the west bank of the Omo River. The area is low-lying, about 380m (1240 ft) above sea level and arid with under 400 mm of rainfall per annum. Precipitation is seasonal, with most rain in April, but occasional falls of generally under 1mm are known in most other months. Temperatures range from around 20°C at night to maxima of around 40°C. A fuller account of meteorological conditions in the area follows later in this report, particularly with reference to the wind régime.

The vegetation cover away from the river is mainly

semi-desert, being grass or thorn scrub savannah on mainly sandy soils; however the river margins, particularly the areas subject to annual flooding, have a narrow but non-continuous belt of riverine tree/shrub savannah on alluvial soil.

The area is inaccessible, having no all-weather road or track connections with the Ethiopian plateau. Heavy materials for the mission are generally delivered once a year by four-wheel-drive truck, which can take about seven days to get there from Addis Ababa. Access to Kenya is physically easy, (the border is only 10km from the mission) but there is no official international border crossing so there are political problems in crossing the frontier at the present time. People and lighter cargo are generally transported to or from the mission by a light aircraft of MAF (the Missionary Aviation Fellowship), based at Jimma. The mission is in regular radio contact with Addis Ababa and MAF and can order any smaller essential items in this way, but freight costs are obviously high.

The water supplies for the "Food from Wind" project and for the mission are derived by pumping directly from the Omo River. This river flows all the year and provides an estimated 80 to 90% of the input to Lake Rudolf with a discharge somewhere between 15 and 25 x 10⁹ cubic metres per annum. The river responds closely to the seasonal rainfall changes on the Ethiopian plateau where it has its sources, being low from December to April and reaching its maximum level towards early September; the annual change in river level in the lower reaches is of the order of 2m.

The only other permanent settlements in the area are a district police post at Kelam, about 9km north of the mission and an EPID irrigation project at Rati, about 15km upstream.

The local people

The local people call themselves Dasanech and they are known officially, in Amharic, as Geleba, (and as Marille in Kenya). They are akin to a number of the Nilo-Hamitic groups found in the region, and traditionally live a semi-nomadic existence, their primary activity being cattle herding. They tend to live in small villages or village clusters varying from a few huts to several hundred. Their huts are beehive-shaped structures woven from twigs and branches and covered in hides and matting (Fig 3). Most of the mill-owners come from a large semi-permanent community that lies alongside the mission, but about half a kilometer from the river.

Their traditional agriculture

Stock raising has always been the main over-riding activity for the Gelebs, but they have traditionally cultivated millet (sorghum), maize and beans plus several types of gourd and tobacco on areas which are seasonally inundated either by river flood-water or by seepage. This has generally allowed them one harvest (in December) from a rather limited area. Grain is stored in raised woven bins on platforms in their villages, but even given a good harvest, losses are great and food has traditionally always been in short supply for the six months of the year prior to the harvest. In common with most similar peoples, they do not normally kill cattle for meat as the size of a herd provides a measure of wealth and a big herd is more likely to survive a period of drought or other adverse circumstances. They do however bleed and milk the cattle. The men traditionally devote themselves to tending the cattle and agriculture is practised primarily by the women and children; crop cultivation is, therefore, to some extent considered to be womens' work.

Chronic food shortages have probably always been a

feature of the traditional Geleb way of life but a number of circumstances have combined to make it even less viable. Firstly the area open to them for grazing their cattle has been reduced by the imposition of national boundaries in the area. A certain amount of international grazing between Kenya and Ethiopia has been agreed, with Geleba going south and Turkana coming north, but they are no longer free to roam into the Sudan at will. Similarly, national governments now attempt to enforce "law and order", and all the local tribes are discouraged from raiding their neighbours' herds of cattle; the police generally make them return stolen cattle. This was a means by which a desperate tribe whose herds had suffered through some natural disaster could restock with the unwilling help of some less unfortunate neighbouring group, not that this was the only circumstances in which cattle raiding took place. The area open to grazing has also been reduced by a southern movement of the range of the Tsetse fly.

The level of Lake Rudolf has fluctuated by about 20m during the last century so that the delta shoreline has moved 60km between 1898 and 1955 which were the maximum and minimum mean-level years, and the level is rising again; as a result certain areas which were cultivable at one time cease to be and vice-versa. Currently, for example, many areas that used to be cultivated upstream of the mission no longer flood. Also, there is a natural increase in population which has no doubt been aided by the medical facilities provided by the mission and the government. These factors can combine to provide increasingly serious food shortages, and it was recognition of this that promoted the American Mission to seek the solution described.

History of the project

The Omo Mission station was founded in 1965, and Mr. and Mrs. Swart lived under canvas for the first three years.

Mr. Ted Pollock, the Mission's builder, designed the mission buildings, including an advanced geodesic (triangulated) dome type of roof construction which has the advantage that the pre-formed triangular roof panels were all air-transportable to the site, (a feature which is important in this area).

Due to the difficulty and expense of supplying diesel fuel for the mission's diesel-electric water pumping system, supporters of the mission in the United States were asked if they could supply a small commercially-available all-steel wind-powered water pump, of the kind commonly found on American farmsteads. This was to allow irrigation of the mission vegetable plots and fruit trees which otherwise demanded excessive consumption of fuel. The supporters in America were more successful than expected with their fund raising, and Dempster Industries who supply wind-pumps were generous with discounts, so that to the surprise of the missionaries no less than four 8ft diameter Dempster multi-blade fan type wind-pumps arrived, two at the end of 1973 and the rest in early 1974.

A number of local Geleb men had been employed by the mission to help with crop cultivation and they had also been encouraged to expand their own cultivation efforts and to try a few new crops. Several of the keener ones were loaned hand pumps to allow them to cultivate on the river bank by pumping water out of the river. The mission, slightly embarrassed by the unexpected glut of windmills, decided as an experiment to set up two of the Dempsters on a plot of Geleb land to allow the people to cultivate an even greater area, and it was this that began the "Food from Wind" programme. The first of the Geleb operated Dempsters was commissioned in April 1974 and is now irrigating about half a hectare which is being cultivated by several families (Fig 4). About three harvests per year of grain crops have been achieved, and rapid-growing fruit trees such as banana and paw paw yield fruit within

about one year of planting.



Fig 4. Dempster wind-mill imported from the U.S.A.

The wind-mills were an immediate success with the Gelebs, which is perhaps surprising when it is considered that these people are almost completely without any formal education and have had very little contact with outside influences or with machinery of any kind. However the wind and the machines are relatively reliable and the people very quickly recognised that this could help provide food all the year around and thereby remove their chronic annual food shortage which had caused them great misery in the past.

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sufficient factory-built machines to satisfy the potential demand as these cost about Eth \$2000 (US \$1000) each, landed at Omo in early 1974, even with discounts. Therefore the Rev. Robt. Swart and Mr. Ted Pollock decided to investigate the possibility of building their own wind-mills and having done a little research discovered the sail-wind-mills that are widely used on Crete for irrigating small plots of land. They both arranged to visit Crete during "stop-overs" when travelling from furlough in the United States, where they photographed the wind-mills and interviewed some of the mill owners.

Fig 5. Typical 11ft diameter sail wind-mills built at Omo Station. (These are now being modified to 14ft diameter).



There is much detail variation in the Cretan designs, so they drew up a design combining some of the best features they had seen and having ordered a quantity of steel and other materials to be sent from Addis Ababa by truck, they began a programme of wind-mill construction. They decided to use steel, primarily because there are no locally available construction materials and timber would have been too bulky to import and also would be vulnerable to attack by termites. A diesel-powered welding set was also brought in as the one major capital investment for the project. Incidentally an attempt was made out of interest to use entirely local materials, these being some scarce local timber or driftwood from the river, plus woven matting for sails (of the kind used to cover Geleb huts), but this original windmill proved difficult to construct; it was too fragile and unreliable in operation.

The first sail wind-mill to be used by a Geleb farmer was commissioned in June 1974 and new ones have been erected at the rate of about one per month since then (Fig 5) although this rate has accelerated during 1975, (see Appendix 1). A number of volunteer helpers came to the mission to work on the project, and Mr. Ted Pollock manufactured the head assemblies at the mission workshops at Ghimeera, as those on the early models were too complicated to construct with facilities at Omo Station. They are then flown down by MAF. The Swarts' son Dick, who has been trained at welding, assembled a large number of wind-wheels and towers prior to his return to the USA, and he also manufactured a series of experimental vertical-axis wind-mills, known as Savonius Rotors or 'S' rotors. This type of wind-mill has been promoted by VITA in the USA and by the Canadian Brace Research Institute, but it is not as efficient as most other types of wind-mill and also intercepts a rather small cross-section of wind. Although Dick Swart's 'S' rotors performed as well as can be expected for that type of machine, it soon became apparent that their performance

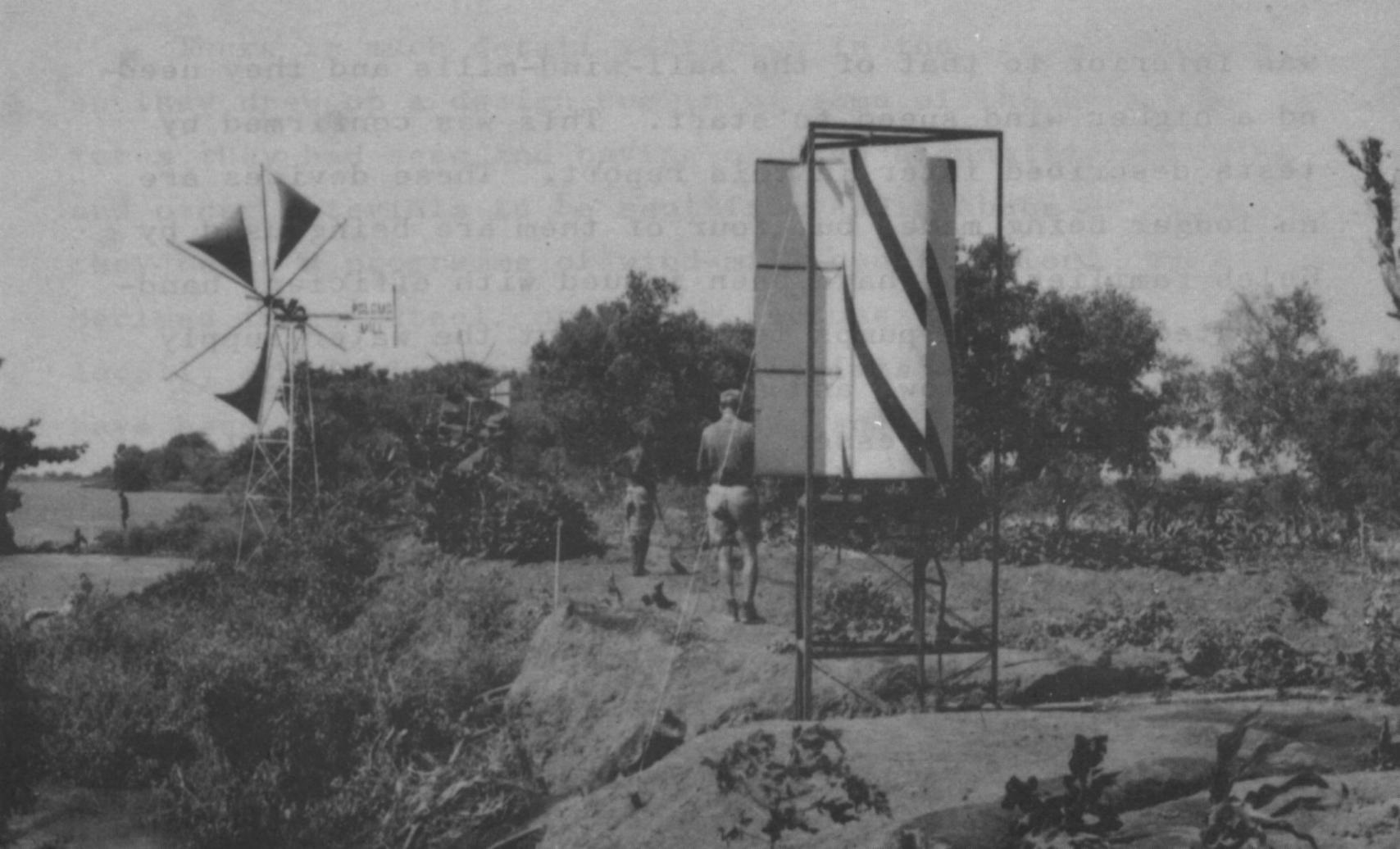
was inferior to that of the sail-wind-mills and they needed a higher wind speed to start. This was confirmed by tests described later in this report. These devices are no longer being made, but four of them are being used by Geleb families, who have been issued with efficient hand-operated diaphragm pumps to supplement the water supply when the wind is low, and a fifth is in use by the mission's medical dresser for his family's vegetable garden.

Quite a lot of development work had already been completed on the sail wind-mills prior to the author's arrival. This included research into the best type of pump, an investigation into different types of sail material and an attempt to improve the performance by increasing the wind wheel diameter from 10ft to 11ft.

Much thought has also been given to distributing this equipment among the Gelebs and to providing the necessary instruction to and support for the users. The mission has set out from the start to try and ensure that aspiring mill owners really wish to use this technology and to aim to minimise their dependence on supervision. A prospective wind-mill farmer has to pay Eth. \$5.00 per year for his wind-mill (the Dempster users pay double this figure) for twenty years; this sum was thought to be sufficient to ensure that any potential user was serious, but to be within the limited means of the local people who have only small sums of money circulating in their isolated subsistence economy.

The mission also has a policy of not employing Geleb workmen for longer than three months at a time, to prevent a dependence on employment being developed, but an exception has been made with one man, called Achao, who has considerable talent for dismantling and assembling the wind-mills. He is capable of organising maintenance and of advising any mill-owners having difficulty, and he operates as a

Fig 6. Savonius rotor or 'S' rotor type of wind-mill (on right) introduced experimentally in early 1975 but no longer being produced since the sail wind-mill (left) can pump twice as much water in the same wind and is cheaper to build.



permanent wind-mill technician.

Any new mill owner gets a kit of equipment in addition to the wind-mill (Fig 7). This includes several hand tools such as a hoe, trowel and shovel, plus a small battery-operated tape-player with a cassette pre-recorded by Achao, which explains the operation of the wind-mill and advocates such ideas as crop-rotation. The new owner is also helped with the initial work on his plot; he and his family must clear the land, but mission staff and workmen install the windmill and help lay out and dig the system of irrigation channels (Fig 8). The mission also provides seed or young fruit trees, although the choice of crop is left entirely to the mill-owner. An American agronomist, Mr. Larry McAuley, arrived at the same time

as the author for an extended stay, and he is advising on various cultivation and crop problems.

Meteorological conditions and data collection

Any reasonably precise prediction of wind-mill performance in a particular location depends on the availability of long-term and detailed data on wind velocities and directions. Appendix 3 shows how wind energy is related to mechanical power; it will be seen from this that the power produced is proportional to the cross-sectional area of the wind-stream intercepted by the wind-mill, (i.e. the area of the wind-wheel) and it is also proportional to the cube of the wind velocity (i.e. a doubling of wind velocity produces an eight-fold in-

Fig 7. The Rev. Bob Swart stands beside the complete kit of equipment that is included with each wind-mill together with all the wind-mill components necessary for a new installation. Note cassette player and hand tools displayed on sail. Head has direct metal-to-metal bearing, wind-wheel is 11ft diameter. Suction hose and float on right.



POLOMO
MILL

Fig 8. Freshly dug irrigation channels for a newly commissioned sail wind-mill, (the new owner and his son on right).

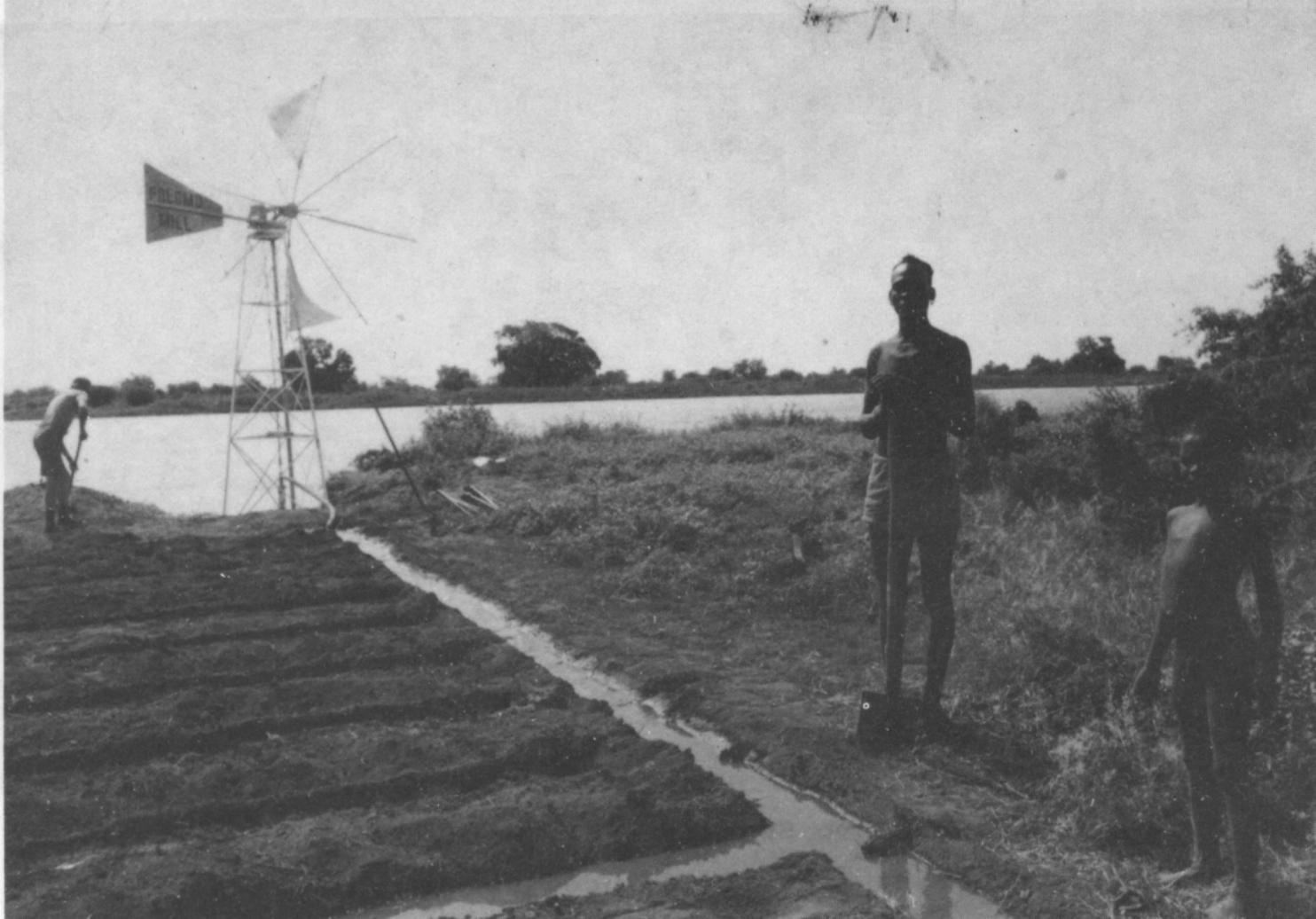


Fig 9. Cup-counter anemometer as used at Omo Station.

The small window displays the total wind run down to the nearest $1/100$ of a mile.



crease in power output, all other conditions being unchanged ($2^3 = 8$). Hence variations of wind speed can have a much-magnified effect on power produced and on the resulting volume of water pumped, (the volume of water pumped will be roughly in proportion to the power produced for driving the pump). Because of the non-linear relationship between wind velocity and volume of water pumped, it can be shown that a widely fluctuating wind régime with a given average velocity will in fact allow more power to be generated than a steady régime of the same average value. Therefore it is important to know not only the average wind-speeds, but also the short term variations that generally take place.

Wind data collection is a statistical science; no two years will be exactly the same, but once data from a succession of years is available, reasonably sound predictions can be made. It should of course be noted that the wind displays certain superimposed cyclic patterns; short term gusts ranging from a few seconds to several minutes in duration; diurnal variations caused by daily temperature changes; seasonal variations caused by changing global weather patterns. Wind conditions in a given place will also vary depending on the height above ground level at which measurements are made and depending on the proximity of obstructions ranging from quite distant hills or mountains to nearby small bushes or tussocks of grass, which can set up local eddies or swirls.

Certain standard equipment and procedures have been determined for recording wind data. Any meaningful wind survey from the point of view of wind-mill specification depends on the collection of wind speed data for several years continuously. Ideally, a continuously recording anemometer on a 10m high pole should be used; in practise this type of sophisticated equipment is usually

only used at major meteorological stations, such as are found at major airports or at institutions conducting meteorological research. Hence it is generally accepted that a useful compromise is to use a simple cup-counter anemometer (Fig 9) which records miles or kilometers of wind run. This is mounted on a 3m high pole (to allow ready reading of the indicator window) and generally it is thought sufficient to take readings three times every day such as at 0700, 1300 and 1900 hours. This allows the wind run for the morning hours, the afternoon hours and the night to be assessed, i.e. average morning, afternoon and night wind velocities can be computed. This is the most commonly used system and due to the few staff free to take readings, it was decided to institute this procedure at Omo Station.

Unfortunately there has been no weather station in the vicinity (the nearest would not give comparable conditions) until the mission was helped to establish one following the inception of the "Food from Wind" project. Equipment has been supplied on loan by the Ethiopian National Water Resources Commission, which runs numerous weather stations throughout the country. At the time of the author's visit, an anemometer, rain gauge and max./min. thermometer had arrived (by MAF flight), but an evaporation pan (which will provide data to assess crop water requirements with more precision) had not arrived as it has to await the next freight delivery by lorry. Therefore wind data is only available for the months from May 1975 onwards, other than a certain amount of data recorded for July and August 1968 by a Chicago University expedition that investigated certain aspects of the Omo delta. There is, therefore, only reasonable certainty of wind conditions for the months May through August of one year at the time of writing. However certain assumptions, reinforced by the subjective opinions of the mission staff in the area are possible. The primary assumption is that the wind régime is not ser-

iously affected by large scale seasonal and continental wind patterns at Omo, partly because the global wind pattern in tropical latitudes (Omo station is at about 5°N) is one of mild wind speeds and there are no marked changes in climate with the seasons in this area. The primary wind régime is diurnal, a "sea-breeze" effect caused by the close proximity of the relatively large expanse of water of Lake Rudolf (the lake extends some 200km from north to south and is up to about 50km wide). The wind mechanism results from temperature differentials between the land and lake surfaces during the day in particular, when the sun rapidly heats the surrounding semi-desert causing a strong breeze to blow off the lake. The effect is less marked at night, when the breeze reverses. The main evidence for this is wind direction data logged by the 1968 Chicago expedition plus the general observations of people at the mission who are used to the wind blowing more often than not, from the south or south east. Wind speed measurements taken in early morning, early afternoon and in the evening indicate highest mean velocities in the morning (usually speeds of 10 to 15 mph (16 to 24 km/hr)) less wind in the afternoon and very little wind at night. The Geleb wind-mill owners are sufficiently aware of this pattern to confine most of their cultivation work to the period from about 0700 to 1200, when good winds can be expected. After this the day gets uncomfortably hot for working and anyway the wind generally falls to a light breeze.

There have been certain local problems in recording meteorological data. One of these is shortage of staff; the local people are illiterate and could not readily be trained to record the necessary readings, hence members of the mission staff must take the readings three times every day. This normally works well, but every now and again some unexpected task or crisis prevents anyone being free to do this at the correct time, so occasional unavoidable gaps in the

record occur every few weeks. These will be less important once a longer period has been logged, but they can effect averages taken over short periods. There is also a major siting problem for the weather station. All equipment must be located within the fenced mission compound area, mainly because otherwise it would be very liable to be tampered with by the local people out of curiosity. Ironically, the success of irrigating the mission land has produced fairly thick tree cover (mainly fruit trees) which has left no area sufficiently exposed to fit the specification for an open wind speed measuring site. The river bank provides a reasonable site so long as the wind follows its normal pattern and blows off the river from the lake, but the exposed area of river bank that is best suited for siting the anemometer is cut off by flooding for a month or two every year, necessitating the removal of the instrument to a more sheltered but accessible spot beside the mission. There seems to be no completely satisfactory solution to this problem, but some suggestions are made in section 5 of this report under the heading "Conclusions and Recommendations".

Land ownership on the Omo River frontage

Although the Gelebs appear to have no concept of land ownership for grazing lands away from the river, nearly all of the river bank frontage, regardless of whether it floods (and is traditionally cultivable) is owned. Ownership generally rests with the more senior men in the tribe, such as the elders, and tends to stay within families. Many of the younger men and some of the poorer or less influential families have no automatic rights to grow crops on the river bank. In the past, areas of the delta newly exposed by a fall in the level of Lake Rudolf or by a change in course of the river were open on a "first come ..." basis, but once occupied, a plot remains the "property" of the original claimant. Despite the Ethiopian government's land reforms that

have been enforced in other parts of the country, the Gelebs traditional river bank ownership continues, mainly due to their isolation. Indeed, it might be counter-productive to enforce land reform on them in the context of wind-mill usage as it is doubtful that they would understand its purpose without an accompanying educational programme.

Because of this, any prospective wind-mill owner must own rights to a site or get permission from someone with a suitable site. There are also a few other natural constraints; some parts of the river bank are sandy or have fissures which prevent the effective distribution of irrigation water, other areas are being rapidly eroded, so that any long-term crops such as fruit trees would be at risk. So, some people with rights to a stretch of river bank may not have a suitable spot for cultivation. A further complication is the existence of stock watering points and places where cattle are traditionally herded into the water to be swum across the river; these also have become established by tradition and cannot readily be blocked off by a cultivated plot. Therefore many of the pioneer wind-mill users are people who happen to have rights to good plots or whose close relations have these rights. Appendix 4 indicates in a little more detail some of the difficulties a few potential mill owners have experienced in finding a suitable plot.

This problem has been mentioned at some length as it seems to be one of the most serious constraints to the expansion of the programme; there are known to be a number of people who would like to have wind-mills but who do not as yet have any rights to suitable sites. As will be explained later, there are some hopes that most of these will eventually be able to get permission to use suitable plots. At any rate a number of senior members of the local clan with land rights have permitted

others to set up mills on "their" land. One man however has tried to charge a rent for land, and although his area would be very suitable for wind-mill cultivation, he has found no one prepared to pay him and it remains unused.

Water distribution and crops

The standard water distribution system is for the water to be delivered by a short length of $1\frac{1}{2}$ " diameter pvc pipe, perhaps 6ft (2m) long, directly to a feeder channel dug at right angles from the river bank across the plot. A series of perpendicular channels are dug from the main feeder and water is fed into each in succession by building small earth dams to direct it, (Fig 8). Every time a channel fills, it is sealed off with a small pile of earth and the water from the feeder is directed into the next channel. Cereal crops are planted along the humps between the channels. Small circular channels are provided around young trees (Fig 10). Most of the plots are about $\frac{1}{4}$ hectare, although they vary somewhat depending on the nature of the site, the crops being grown and the ambitiousness of the owner and his family.

Some plots are more porous or have cracks and fissures which cause losses of water, but probably one of the primary variables in the efficiency with which the pumped water is distributed lies with the owner of the plot. Some seem to have grasped the best way to distribute their water and their crops look fairly even, others, in fact the majority, tend to over-water the rows nearest to their mill and to under-water the furthest rows; in such cases the crops nearest to the mill are noticeably taller and greener than those further back. Efforts are being made to overcome these mistakes by education; it is in fact not at all surprising that there should be some difficulties of this kind for

people using what is for them an entirely new technique (the floodlands they used to cultivate did not of course require any irrigation, but only yielded one annual crop).

Human nature being as it is, the Gelebs are generally rather prone to try and grow traditional crops they are familiar with; prestige crops being grains such as millet and maize. One of the pioneer mill-owners has grown five maize crops in succession in about 15 months on the same plot; not surprisingly they have got progressively worse both due to soil depletion and due to the spread of a corn bore beetle. The mission does not enforce any kind of crop growing policy, but attempts to guide the mill-owners instead. This man after his fifth harvest has apparently recognised the mistakeness of his cultivation; one of the primary lessons that Mr. Larry McAuley is trying to get across is the need for crop rotation. He is hoping to get some mill-owners to divide their plots into four and rotate corn-legume-corn-fallow on each quarter.

The mission has introduced a number of new crops some of which have found ready acceptance, including sweet potatoes, bananas, paw-paws (papayas) and mangoes. Fruit is a new introduction in this area and is particularly well liked. It seems that a number of the mill owners have recognised that fruit trees are a good investment for the future, as they need less attention once established and provide shade for other crops, although fruit bats and birds are beginning to discover the new trees and may well prove a problem in the future.

The Gelebs have always had a local strain of bean, but the mission is seeking to introduce soya beans as it is thought they will produce a better yield, they will provide a useful source of protein and, will also be very suitable for crop rotation with the favoured traditional grain crops. The Rev. Swart organised a special gather-



Fig 10. Method for irrigating young trees, (note Savonius Rotors in background, 2 bladed on left and 3 bladed on right).

ing of all the mill-owners, plus their immediate families and associates, both to offer an opportunity of letting them sample soya beans as well as to introduce the author and Mr. Ted Pollock (who arrived a few days after the author) and to give the Gelebs a chance to mention any problems they were having with their mills. The soya beans were fried by Achao's wife on a typical Geleb open fire using their familiar utensils, to make it clear that they could readily cook them themselves, and they were well received (see Figs 11 & 12). This illustrates a problem inherent in introducing any new food needing preparation; the people do not automatically know how to cook it and prepare it, so that this kind of exercise was clearly a useful and essential part of the programme. In a few cases the local people invent their own dishes; Achao's wife, for example, adds pounded ground-nuts (another new local crop) to her maize-meal porridge (a traditional food) making a more nutritious dish which is apparently popular with her family.

3. AN APPRAISAL OF THE OMO "CRETAN SAIL" WINDMILL DESIGN

By the time of the author's visit a number of the problems that were apparent earlier in the year, notably the choice of pump and of sail material had been satisfactorily resolved and a reasonably standardised design had been adopted and put into production. Up to about April 1975, a variety of different ideas were being tried out with varying degrees of success, including the use of vertical axis Savonius rotor type wind-mills.

The entire sail wind-mill system can be subdivided into a number of primary components (see Fig 7. which shows all the parts laid out on the ground). These are the suction line/foot valve, the tower, the pump and connecting rod, the head assembly and tail and lastly the

wind-wheel and sails.

Suction line and foot valve

All the wind-mills draw water from the river through a $1\frac{1}{2}$ " (36mm) diameter thick-walled, but flexible, pvc plastic pipe. The pipe is securely attached to the suction (lower) end of the pump with an adjustable pipe clip and carries a factory-manufactured brass foot-valve at its lower end. The foot-valve is supported by a float consisting of a block of expanded polystyrene (Styrafoam) jammed into half an oil barrel; the float is essential to prevent the foot-valve getting clogged with silt, as would happen if it lay on the river bed. A glance at the cost break-down (Appendix 2) shows that the entire suction line/foot valve assembly costs about Eth \$185, which is about 25% of the entire material cost of the wind-mill. However it is not really practicable to omit or reduce parts of this assembly; attempts have been made to save the cost of the Styrafoam and oil-drum half (worth Eth \$22.50) by using a log of wood as a float, but there is not much wood available that is sufficiently big and buoyant, and any that have been used deteriorate rapidly and become water-logged despite all efforts to prevent it. It is not practical to try and support the foot valve on a stake driven into the river bed, because the river is deep and fast-flowing when in flood (and carries large branches and logs which could up-root any stake); also the level varies considerably and a wooden stake would be susceptible to water-logging and rotting. Similarly, the pvc pipe, which costs about Eth \$90 for the suction line, is an expensive but not readily alterable component, (it should be mentioned that this piping is manufactured in Addis Ababa, although the pvc raw material must presumably be imported by the extruders). A foot-valve can be improvised, (in fact a home-made one was tried), but unless it functions efficiently the pump loses its prime and has to be constantly refilled with

water, which makes the entire wind-mill operation more difficult and less reliable. Hence it seems justifiable to invest in a precision-machined component for this function. The half oil drum is only necessary to protect the Styrafoan block, and although by no means cheap at 10.00 is probably the cheapest suitable casing available. Therefore, although the float system is rather expensive, it is extremely reliable (in that it rarely causes trouble) and is effective.

Tower

The tower is a completely welded assembly and forms a single rigid component when completed. This has the advantage that no foundations are necessary to ensure accurate alignment of the tower footings, which can simply be embedded in impacted soil. The original tower had four corners, but this was modified to a three-cornered tower at an early stage, thereby saving one 12ft length of $1\frac{1}{2}$ " x $1\frac{1}{2}$ " angle per tower without any excessive loss of strength. The lateral members are lighter 1" x 1" angle with cross-bracing of $\frac{1}{4}$ " concrete reinforcement rod. Although the towers are possibly somewhat stronger than is strictly necessary for structural integrity, there is no effective way of significantly reducing the number of cross-braces without removing their secondary function of acting as ladders. The mill-owners have to climb the towers to fix the sails on when starting their wind-mills and also to stop the mill by pulling the tail sideways to the wind; since access may be needed from any side of the tower to avoid the side where the wheel is turning, a symmetrical structure is important. At times when there is insufficient wind the Gelebs often climb the towers and turn the wind-wheel by hand and again, this would not be possible if there was not such a good selection of horizontal members. As the tower is only 12ft tall, there is no way of reducing its cost by making it any smaller. In the circumstances, bearing in mind the relative indestructive-

ness of the towers and their likely long useful life, they seem to have evolved, even at Eth \$ 200, into a reasonably cost-effective component. (Some further observations on tower design follow in the section on the author's work programme, in which he investigated a possible tubular tower).

Pump and connecting rod

Factory made semi-rotary, diaphragm and piston pumps were evaluated in early 1975. Of these the most satisfactory proved to be a piston pump, manufactured by Dempster Industries specifically for wind-mill operation. Because the mission is able to obtain this pump with a 50% discount from the manufacturer, it costs only Eth \$80.00 landed at Omo Station. It performs most reliably and efficiently and no pump of similar performance and reliability could be manufactured locally for a comparable price. It should be mentioned that Dempster originally supplied a 3in diameter cast steel pump with a brass cylinder lining and gun-metal bucket and valve components, plus a single leather washer. However, they then substituted an alternative 3" diameter pump with a thick-walled pvc cylinder and two leather washers on a similar gun-metal bucket. The disc valves in both cases were of gun-metal and brass. This pump is slightly cheaper and appears to function with virtually no apparent wear after a year of operation. Both types of Dempster cylinder are in use plus one 2 $\frac{1}{2}$ " diameter cast iron piston pump of Indian manufacture that cost slightly more but was available ex-stock in Addis Ababa; this however wears leathers rather faster, as is common with iron or steel cylinders, and due to its smaller bore has a markedly lower delivery rate. All the Dempster pumps operate with a stroke of 7in on sail wind-mills and with a reduced 5in stroke on the Savonius rotors, which are incapable of starting if the linkage is set to produce a 7in throw.

The outlet from the pump is generally via a

standard "T" pipe fitting, with an olive-wood plug bored to take the pump plunger as the only sealing device. As will be explained later, this is not entirely satisfactory and a number of modifications are proposed to reduce water leakage.

The pumps are driven from the tower head by a connecting rod, made from $\frac{3}{4}$ in black water pipe. A simple ball and socket joint was developed by Dick Swart to allow for non-alignment of the head and pump and to allow the top part of the connecting rod to turn with the wind-mill head when it moves to face changing wind-directions, and this also forms the link between the pump rod extension and the connecting rod. The pump rod extension is kept in alignment with the pump by a wooden cross-head, this being a plank that straddles the tower at the correct level with a hole bored in it for the rod. The top of the connecting rod has a split piece of water pipe welded to it, with reinforcement flanges to support it and prevent buckling. The split water pipe has two drilled lugs to allow it to be bolted around the crank journal on the head. Although steel to steel plain bearings of this kind are not sound engineering practice, the loads transmitted are quite low and no serious wear has yet occurred at this point on any of the mills. Lubrication is by heavy grease, which seems to last without replacement for a considerable time. The split bearing is mounted with its axis suitably inclined to allow for the slope of the mill-wheel shaft.

Head assembly and tail

The head assembly consists of an angle-iron frame carrying two mountings for the main shaft bearings and the side members extend backwards to include an integral tail unit. The frame rides on a $1/8$ "x $1\frac{1}{2}$ " flat-bar ring of 12" diameter welded into the top frame of the tower; earlier models had a square sub-frame made of $1\frac{1}{2}$ "x $1\frac{1}{2}$ "

square section steel tube slotted to carry four flanged wheels made from 1" water pipe and washers, which rolled around the flat-bar ring in the top of the tower (Fig 13). Problems were experienced with this frame, which could not readily be fabricated at Omo Station (they were made by Mr. Ted Pollock at his workshop in Ghimeera); also there was difficulty in getting sufficient grease into the wheel hubs so that the flanged wheels tended to wear the bolts acting as axles rather rapidly and also did not turn freely. As a result some mills were tried with the head frame angle iron chassis lying directly on the tower ring, which with plenty of grease seemed as good as the arrangement with small wheels as far as resistance to turning is concerned. The head is prevented from lifting by four hooks bent from flat bar which project down through the centre of the frame and curve round underneath the ring in the top of the tower. When the square frame carrying the frame was omitted, new shorter hooks were introduced to allow for the lowering of the frame by just under 2", and the connecting rod had to be shortened similarly.

The problem of devising a satisfactory head support bearing was tackled under the author's work programme and resulted in the evolution of a new type of roller head bearing described more fully later on, (see Figs. 13 & 14 which shows the two different types of head bearing).

The main shaft is carried at its rear end by a self-aligning sealed ball-race in a metal housing and at the front by a plain olive-wood bearing, split horizontally and packed with grease. A few mills have either both bearings wooden or both ball-races. Within the time-scale so far experienced there is little to choose between the two types of bearing; olive wood is theoretically cheaper, but the mission was given a consignment of 100 sealed ball-bearings. One of the advantages for

putting one of each type of bearing on each mill is that it will eventually allow a ready means of comparing the durability of the two types. The friction of the wood bearing is probably marginally higher, but it is sufficiently low to prevent undue heating of the bearing blocks and it has no measurable effect on wind-mill performance.

The shaft is made from a length of approximately $1\frac{1}{4}$ " hexagon bar; the cross-section being not from choice but because it was the only sufficiently strong bar available from the steel suppliers in Addis Ababa. The hexagon cross-section caused problems in that a piece of water pipe has to be welded around it where it passes through the wooden bearing, and it needs to be laboriously ground and filed to fit the steel ball-race at the rear end. The few mills with ball-races for the front bearings had to have them fitted by cutting the shaft, grinding and filing to take the ball-bearing and then welding the cut-off end back after fitting the race, which was one reason to favour wooden bearings at the front. A last point on bearings is that the lip where the shaft was filed to fit the rear bearing acts as the thrust surface to take axial thrusts from the wind-wheel.

The shaft was cut so as to permit two pieces of $\frac{1}{4}$ " steel plate to be used to offset the crank journal, these being butt-welded to the cut shaft ends. "Counterbalances" were added to the opposite ends of the crank webs on the suggestion of a volunteer, but this in fact serves no purpose and a resulting recommendation is to omit them in future. The fabrication of crank shafts was another task carried out in the workshops at Ghimeera, as local facilities at Omo are not suitable for readily achieving the correct alignment.

The front of the main-shaft carries a hexagonal flange drilled to match the hub of a particular wind-wheel, (the hub and flange are drilled together to ensure they will fit exactly).

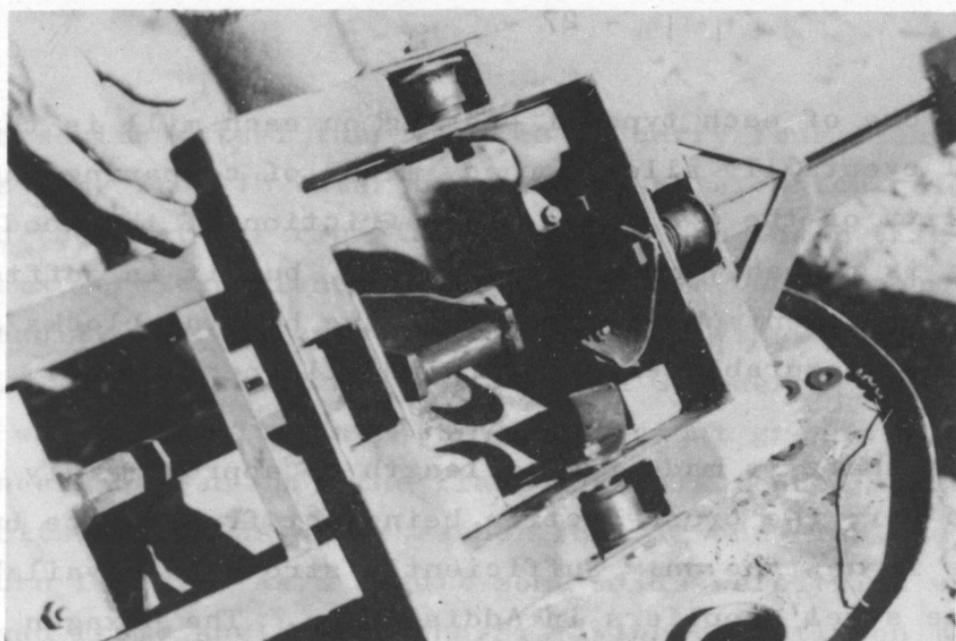


Fig 13. Original square head sub-frame running on flanged wheels.

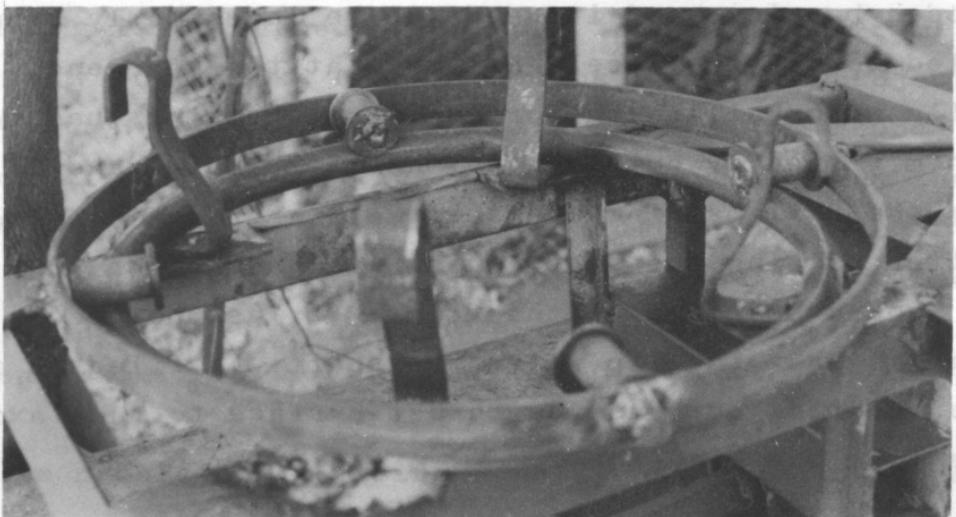


Fig 14. Modified system running on rollers.

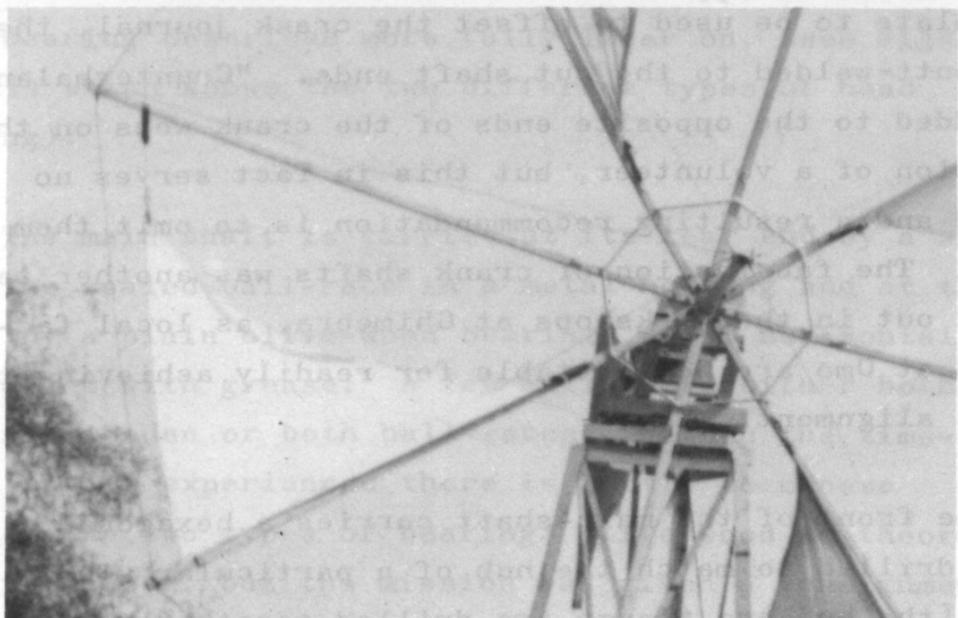


Fig 15. Close up of sail arrangement.

The tail unit is carried on a pair of $1\frac{1}{2}$ " x $1\frac{1}{2}$ " angles cantilevered from the rear of the head frame; it consisted of a suitably shaped panel of flat galvanised sheet steel bolted between the flanges of the tail boom with extra vertical flat-bar stiffeners. Certain modifications to the design of the tail unit are also proposed for reasons to be discussed in detail later in this report.

Wind-wheel and sails

The wind-wheel follows the classic Cretan type of pattern, with a number of arms radiating from a central hub which carry the leading edges of a series of triangular textile sails. The whole structure is braced with wires radiating from an extension to the shaft mounted on the hub to prevent axial distortions of the arms and by wires connecting the tips of the arms to control radial movements. The trailing corner of each sail is sheeted to a point on the preceding arm (Fig 15).

Most of the Omo sail wind-mills have eight arms, allowing provision for eight sails, although one was made with six arms as an experiment. The arms are of $\frac{3}{4}$ in black water-pipe and are curved forward slightly, giving a negative coning angle, in order to give as much clearance between the wheel and the tower as possible (the inclination of the main shaft helps with this too). The wheels were originally built to an overall diameter of 10ft, (3m), but this was modified to 11ft early in 1975 in an attempt to improve wind-mill performance. The central extension from the hub, to carry the bracing wires, is generally made from two lengths of 1in x 1in angle welded with their flange ends in contact to make a square cross-section, and the bracing wires consist of standard galvanised fencing wire.

Various types of cloth were tried for making sails,

but most standard woven textiles proved inadequate. This is because any flexible material is inclined to flap and crack in gusty wind conditions and most materials are susceptible to rapid degradation under continuous strong sunlight, the ultra-violet part of the spectrum being responsible. A further problem with most materials is a tendency for a tear to run rapidly once initiated. Therefore it is clear that a heavy, relatively inflexible, run-resistant and u.v. resistant material is essential for sail wind-mills if frequent sail replacement is to be avoided. The mission was fortunate to be able to obtain a large roll of Dacron sail cloth, a synthetic material specially formulated for yacht sails; this would normally be rather expensive compared with most textiles, especially landed at Omo station; however their stock was donated by the manufacturers Dupont Chemicals of the USA. A nylon kite material was also evaluated, but being flimsier than the Dacron it was prone to flap in gusts and would be unlikely to last as long. To date none of the Dacron sails have torn in use, although stitching occasionally needs replacement. The thread used for hemming the sails needs to be equally strong and resistant to u.v. degradation, so an extremely strong synthetic (nylon) thread is used. Cotton is not generally strong enough and long-lasting enough for this service.

Sails on the traditional Cretan wind-mills are generally reefed by rolling them around the arms of the wheel, but this is not a practical means in southern Ethiopia as cloth, being a rare and valuable commodity in this locality, is likely to be taken during the night if a mill were left unattended with reefed sails on it. Also it is a trickier operation to wrap sails around the arm than to completely remove or refit them. Therefore an ingenious method of fitting them had been devised by the Rev. Bob Swart, in which rubber loops cut from motorcycle inner tubes are attached to the corners of each sail with lengths of polypropylene rope; the sails can then very rapidly be fitted or removed by attaching the loops

onto metal hooks welded at suitable points on the arms of the wheel. The rubber allows for any inaccuracies in the sail or wheel and keeps the sails stretched into an effective shape for catching the wind. This system has a number of important advantages; firstly it allows rapid adjustments to be made to the area of sail being carried if the wind strength varies, (it was noticeable that the Geleb mill-owners learnt quite quickly to put an appropriate number of sails up; they did not try and over-do things by putting all their sails on regardless and it is a common sight to see mills operating effectively with just two sails when a good breeze is blowing); secondly, no mill-owner will leave his mill with sails on and unattended for fear of losing them. When work finishes for the day the people remove the sails and go back to the village with them; therefore there is no risk of a wind-mill being damaged by an unexpected increase in wind-strength while left in operation unattended. The Savonius rotor wind-mills, being all metal, are quite often left in operation by their owners and have been damaged by sudden storms before staff from the mission could get out by motor-cycle and stop them, (this is partly because the Savonius rotor pumps rather less water and there is a resulting temptation to leave it running to make up for this. When this happens it is not possible for the owner to return to switch it off quickly as most of them live about one hour's walk from the cultivated plots).

A number of modifications to the wind-wheel have been tried and certain recommendations follow; most of these were aimed at gaining improvements in pumping performance, particularly in low wind conditions.

4. WORK PROGRAMME-21 JULY TO 16 AUGUST 1975

Identification of problems

Analysis of the various features of the sail-wind-mills at the state of evolution just described revealed a number of technical problems needing attention; these can be summarised as follows:-

- (i) a need for an improvement in pumping performance, particularly in low winds
- (ii) wind-wheel orientation to face changing wind directions was not entirely satisfactory, especially when six or more sails were fitted
- (iii) lack of an adequate seal at the point where the pump rod enters the top of the pump precluded the delivery of water against a head of more than a few inches
- (iv) a need to minimise the cost of the system by reducing the size or modifying some of the components
- (v) consideration of alternative sail materials in case the supply of free Dacron ceased to be available
- (vi) a need to find a straightforward, but meaningful method for testing wind-mills, so that the relative merits of any modification can be objectively evaluated

A number of operational problems also became apparent:-

- (i) the need to obtain permission to set up a wind-mill from "land-owners" in cases where a pros-

pective user has no traditional rights to the river bank

- (ii) inefficient water distribution and wind-mill utilisation
- (iii) poor choice of crops and lack of understanding of crop rotation

The search for solutions

Various ideas were tried to introduce improvements, with differing degrees of success. It is worth describing all of these even though certain innovations were abandoned either because they were not wholly satisfactory as solutions or because they introduced further complications. The successful innovations are discussed in more detail under "Conclusions and Recommendations", together with some suggestions for further development work that these point to.

(i) methods for improving pumping performance

One of the only complaints voiced consistently by the Gelebs was that the sail wind-mills did not pump enough water when the wind was low; they tended to set their standards by the performance of the Dempster factory-built wind-mills which would start in a very low wind as a result of being fitted with rather too small a diameter of pump for the low lift called for and being geared down. The Dempster mills are also on 25ft tall towers giving better access to the wind. One thing not apparent to the casual observer is that, through being geared down, the pumping rate of the Dempster is not as fast as a directly linked wind-mill.

Increased wheel sizes and double-acting pumps

Therefore an early objective was to modify a sail wind-mill so that it would clearly outpump a Dempster and start in similarly low winds. This was achieved by increasing the wheel diameter so that a greater cross-section of wind intercepted would compensate for other shortcomings. Hence a standard 11ft sail wind-wheel was enlarged to an overall diameter of 16ft by welding on extensions to the arms (see Fig 1). For convenience the same sails were used and the attachment hooks were moved outwards to allow for this. Therefore the full benefit of the enlargement was not completely realised as less of the centre of the swept disc was being exploited, although most of the power of a wind-mill is derived from the outer parts of the swept disc. The 2ft 6in increase in radius should provide an increase in starting torque (due to the extra "leverage" of the sails on the shaft) in proportion to the extension of radius, that is by a factor of $8/5\frac{1}{2}$ or about 45%. Similarly, an increase in power proportional to the increase in swept area is to be expected (power is proportional to area, see Appendix 3), and this works out at a ratio of 134:78 or 72%. This modification proved satisfactory in that the 16ft diameter sail wind-mill not only started in lower winds than the Dempster, but was capable of outpumping it at a rate approaching 2 to 1 (measured by strokes per minute of the identical diameter pumps). (See Appendix 5). One disadvantage was that the outer edge of the wheel was now only 5ft from the ground and proved to be a serious hazard should anyone accidentally walk into it, therefore it was decided to make 14ft diameter wheels as a compromise, although one 15ft diameter one was built. The 14ft and 15ft wheels give an improvement in starting torque of about 27% and 36% respectively, with power increases of 43% and 55% respectively when compared with the original 11ft wheels (and rather better than this compared to the earlier 10ft wheels).

A parallel experiment consisted of the building of

a completely different wind-wheel with four large rectangular sails designed to be aerodynamically more efficient than the sail arrangement on Cretan mills, in other words an attempt to intercept more wind, more efficiently, (Fig 16). The sails on the experimental design were mounted on a metal frame which held them more rigid and gave the sail surface approximately the correct angle of attack to achieve reasonably efficient lift at all points along the radius; the characteristic twist common to all propellers. This wind-wheel was built to be 18ft in diameter and the inner ends of the sail surfaces were nearer the shaft to extract as much wind-energy from the swept-disc area as possible. This machine proved to be rather more powerful than the other mills, so much so that it was difficult to control or to pull out of the wind. The blades were mounted so that they could rotate about their axes in tubes radiating from the hub, and there were rubber loops fitted in the hub to provide control forces so that the blades would partially feather by going into a coarser pitch in high winds (Fig 17). The wheel disc was rather too large to be controlled by the standard wind-mill tail, so as an added innovation, this mill was run downward of the tower without a tail, and this worked reasonably well with the head displaying considerable sensitivity to changing wind-directions. This experimental wheel was later used in conjunction with a number of other innovations, to be described later, but it was later abandoned mainly because the 14 and 15ft Cretan wheels seemed to be quite adequate, and being braced with wire, they seemed stronger and less prone to get damaged and their sails were easier to fit or remove. Nevertheless this experiment did point to ways in which considerably more power might be extracted from the wind in areas with lower winds than Omo, or where higher pumping heads are required, although it should be stressed that further development of this design would be called for.

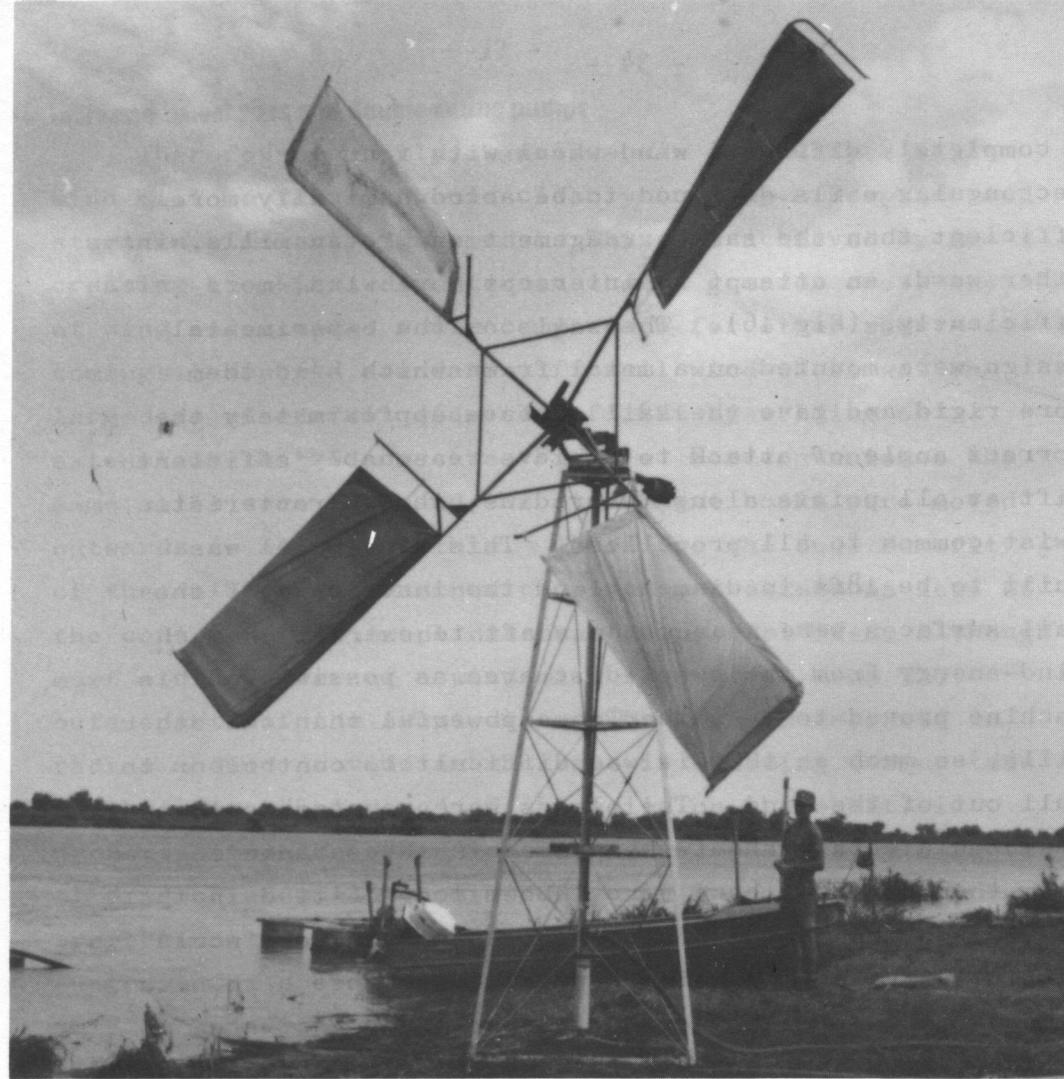


Fig 16. Experimental 18ft diameter four-sail wind-mill with feathering blades operating downwind of the tower.

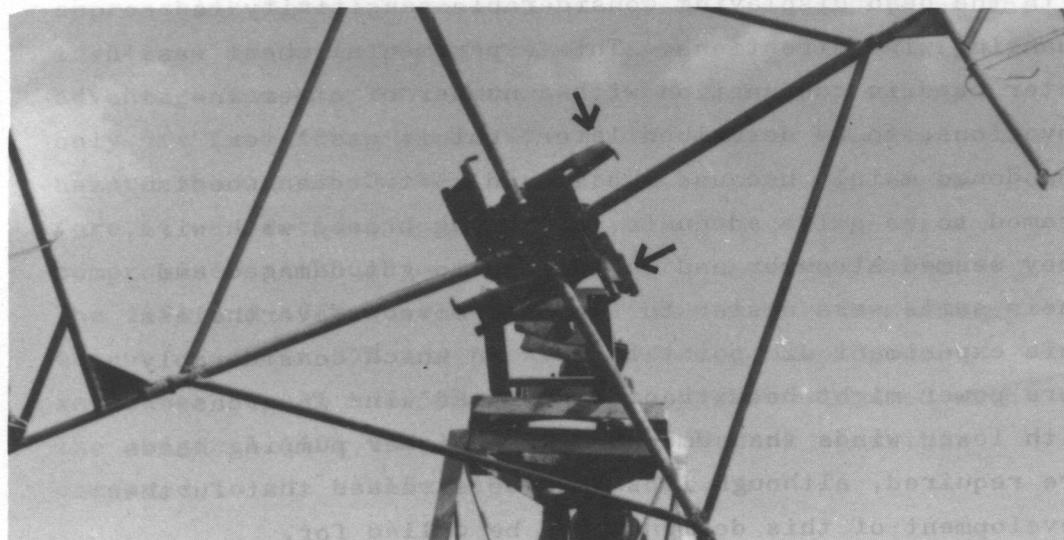


Fig 17. Rubber loops were used to restrain sails in feathering mechanism.

Another method of obtaining a considerable improvement in pumping performance is to use a double-acting rather than a single-acting pump, (i.e. arranged to deliver water on both the up and the down stroke). All the available pumps were single-acting and could not readily be modified to be double-acting with materials on hand, so this approach was simulated by mounting two single-acting pumps under a wind-mill, arranged in such a way that when one was on the up-stroke the other was on the down-stroke, using a rocking beam installed by Ted Pollock (Fig 18). As will be seen under the discussion of the test results, this mill was capable of delivering fully double the volume of water in a given wind using both pumps, compared with when one of the pumps was disconnected. In fact this mill achieved the best performance under any of the tests of just under 1300 gallons per hour against a static head of 9ft with a wind speed of $14\frac{1}{2}$ mph (using the experimental 16ft diameter wheel fitted with only four sails), (see Appendix 5).

Improving wind-wheel orientation

The high drag of a wind-wheel, particularly when carrying a lot of sail, tends to make it try and turn itself around to the rear of the tower; the function of the tail vane being to fight against this tendency. Directional stability was not completely satisfactory with the smaller 11ft diameter wheels, but the enlargement of wheel diameter just described rendered the previous tail design quite inadequate. With poor directional stability the wind-wheel could frequently only receive wind at some acute angle to its plane of rotation, thereby losing much of the advantage gained from increasing the diameter. Also, the 12ft towers are rather low and in not always ideally exposed situations, so the wind tends to veer and gust. Therefore it is important to have a machine capable of responding rapidly to changes in wind direction if the maximum efficiency is to be obtained from the wind-wheel.

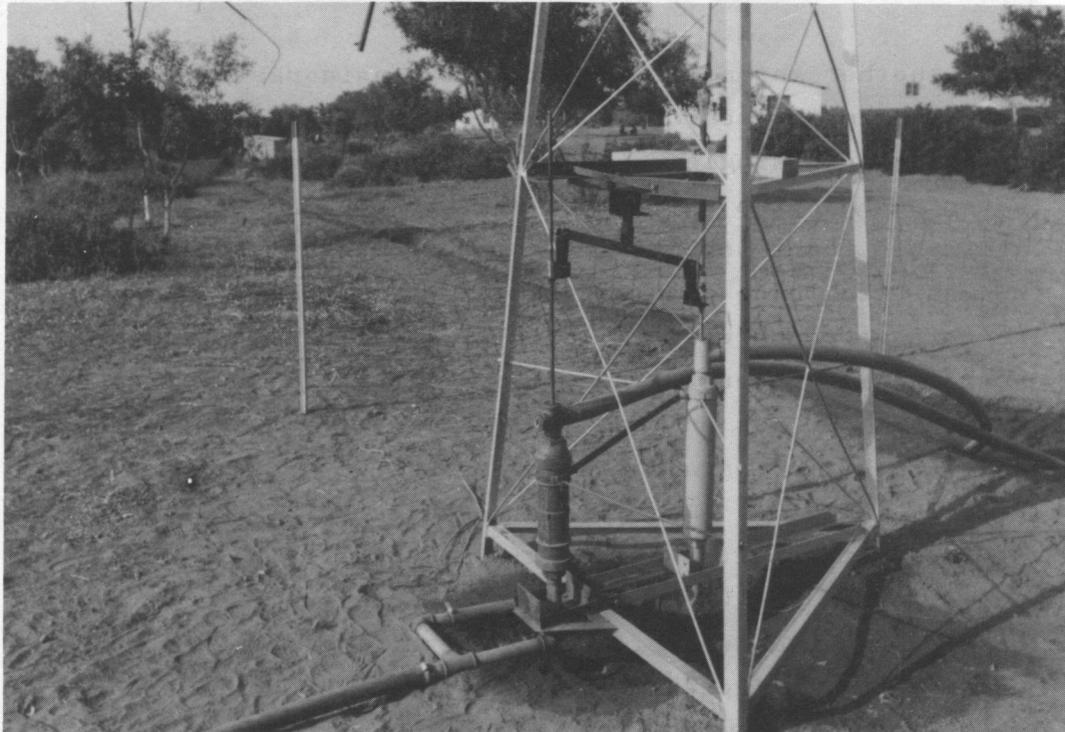


Fig 18. Double pump arrangement.

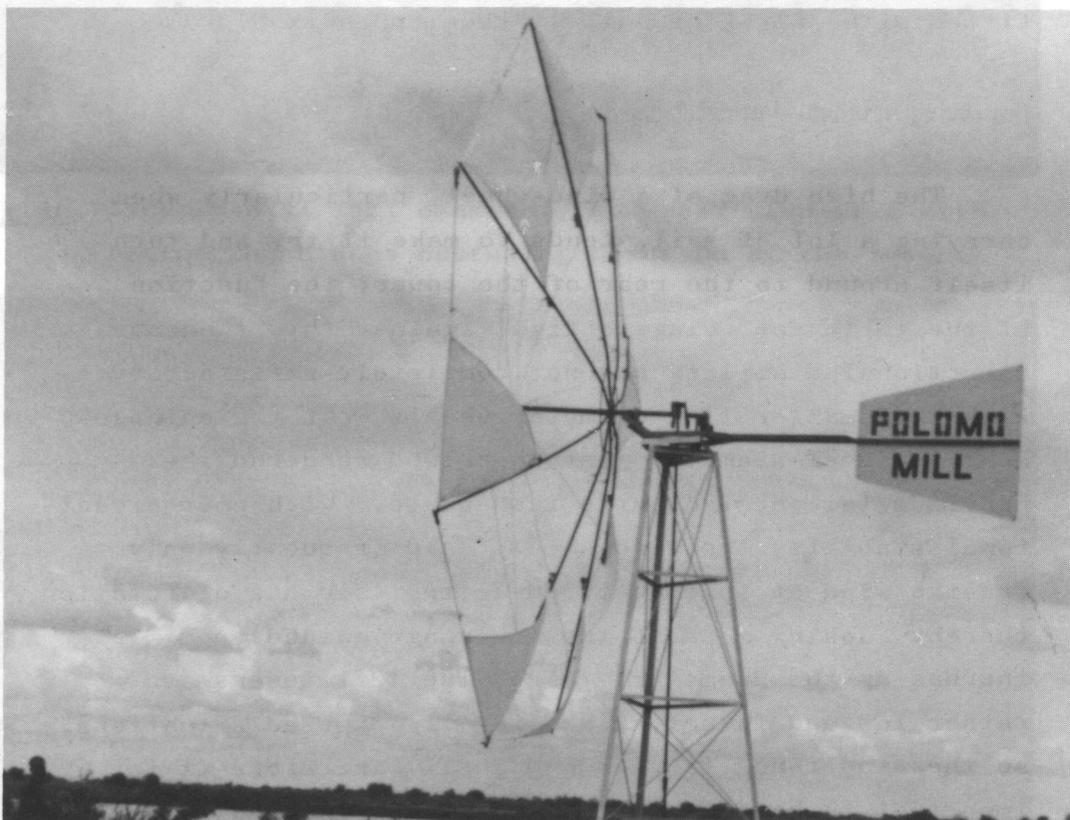


Fig 19. Interim extended tail.

Therefore the original tail was cut off and refitted on an extended tail-boom, to increase its effective leverage; the increased size of the wind-wheel at the other side of the turntable tended to compensate for the increased weight acting on the rear of the turntable. However, as this did not produce sufficient improvement, an additional area of metal was added to the rear of the tail to increase its surface area and to further increase its leverage slightly (Fig 25). This did improve the situation somewhat, but introduced a new problem in that the whole turn-table/head assembly was now too tail heavy, which caused the turntable to rock backwards and engage the front pair of hooks under the tower ring, thereby increasing the general friction at the turntable and reducing much of the effect of the improvement in tail leverage.

Because of this we scrapped the original tail design and built a new, larger rectangular tail vane, carried on a lighter and longer tail boom (Fig 20), this being fabricated from thinner-sectioned square tubing and triangulated to compensate for any loss of strength. This was introduced in conjunction with an improved design of turn-table bearing, allowing the head to run on rollers instead of either axled-wheels or straight metal-to-metal surfaces. The roller bearings (Fig 14) consisted of several short lengths of pipe guided by a light cage made from a ring of flat-bar with stub-axle guides for the rollers. As in this case the axles are not loaded by more than the weight of the cage, there is much less friction than when using flanged wheels, and this modification produced a marked improvement in response to changing wind conditions when used in conjunction with a 15ft diameter sail wind-wheel. This tail was built as a compromise using available materials, but as detailed later under the recommendations, it is suggested that its concept can be extended to obtain further improvements.

Fig 20. Recommended 15ft diameter wind-mill configuration with lightweight extended tail vane and head running on roller bearing (see Fig 14).

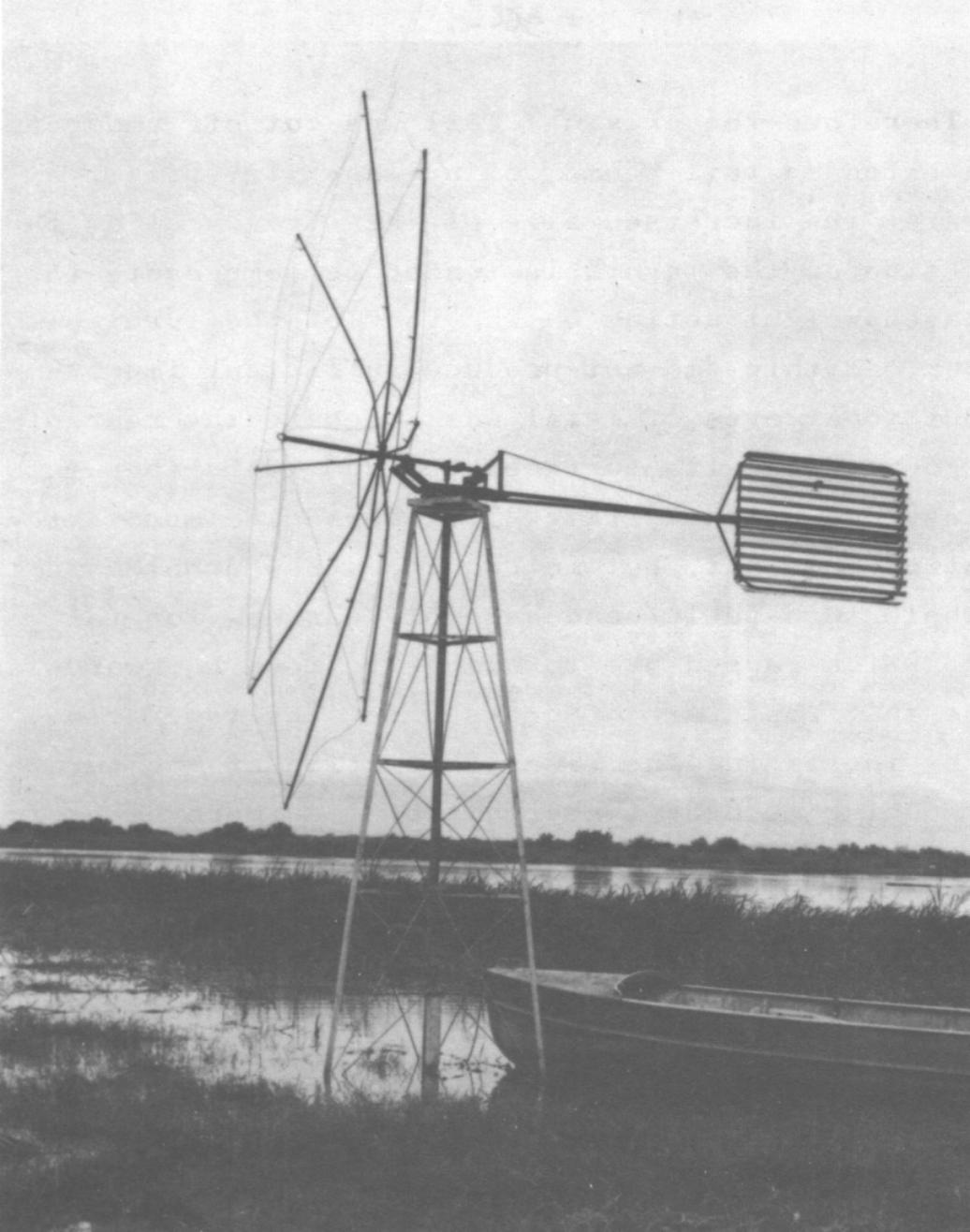
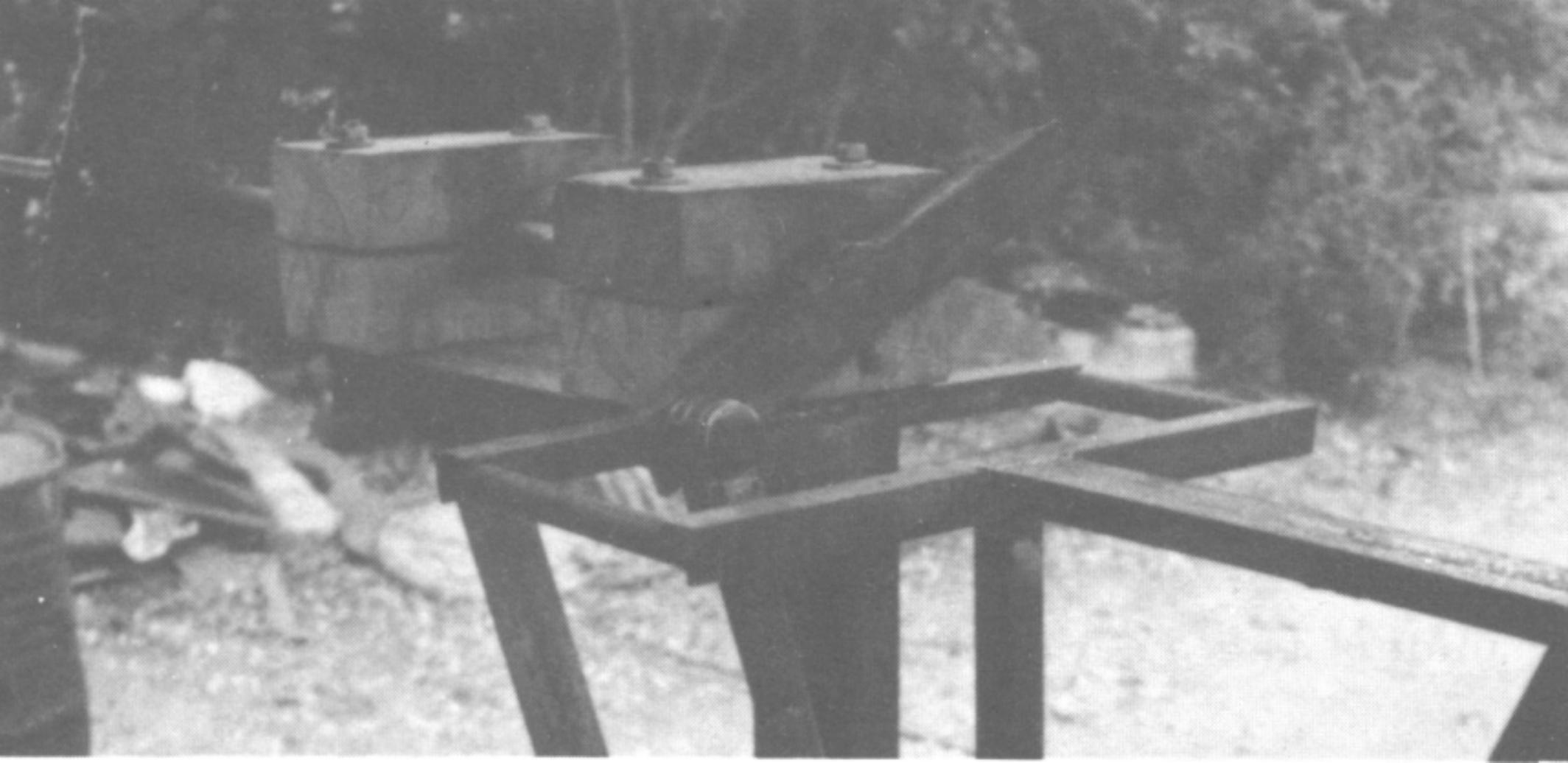


Fig 21. Transmission system for tubular tower wind-mill.



Other work carried on in parallel to this, included the omission of a tail completely on the special four-bladed wheel, both to obtain very high degree of sensitivity to changing wind directions gained through running the wheel downwind of the tower and to reduce the material content of the device. However the standard Cretan type wind-wheel does not lend itself to be used down-wind of the tower as the simple and cheap bracing wires which are in tension when the wheel is up-stream of the tower, would need replacement by solid struts capable of resisting compression. This would remove much of the saving gained from removing the tail and introduce the need for extra balancing on the opposite side of the turntable to compensate for the heavier wheel.

Another indirect approach to the problem was to tackle high turning resistance between the turntable and tower head by reducing the diameter of the head, because the friction resistance to rotation is proportional to the mean diameter of the support bearing. To do this involved a complete change in the tower and head design, as the large diameter is needed with the existing arrangement to allow clearance for the pump connecting rod where it passes into the tower when the crank journal reaches the lateral extremes of its throw. Therefore the opportunity was taken when developing a tubular tower (Fig 22) to include a redesigned transmission (Fig 21) involving the use of a much shorter connecting rod. This allowed a 3in diameter head bearing to be used, consisting of the bottom end of the turntable tube resting on a ring-shaped lead thrust block supported on the tube tower. Although the tower design was abandoned for reasons to be described, the small diameter turn-table turned very easily and was both low in material content and simple to build. But the successful later development of a roller bearing (previously described) removed the need for this other development and involved fewer changes in the existing and proven design, to which considerable volumes

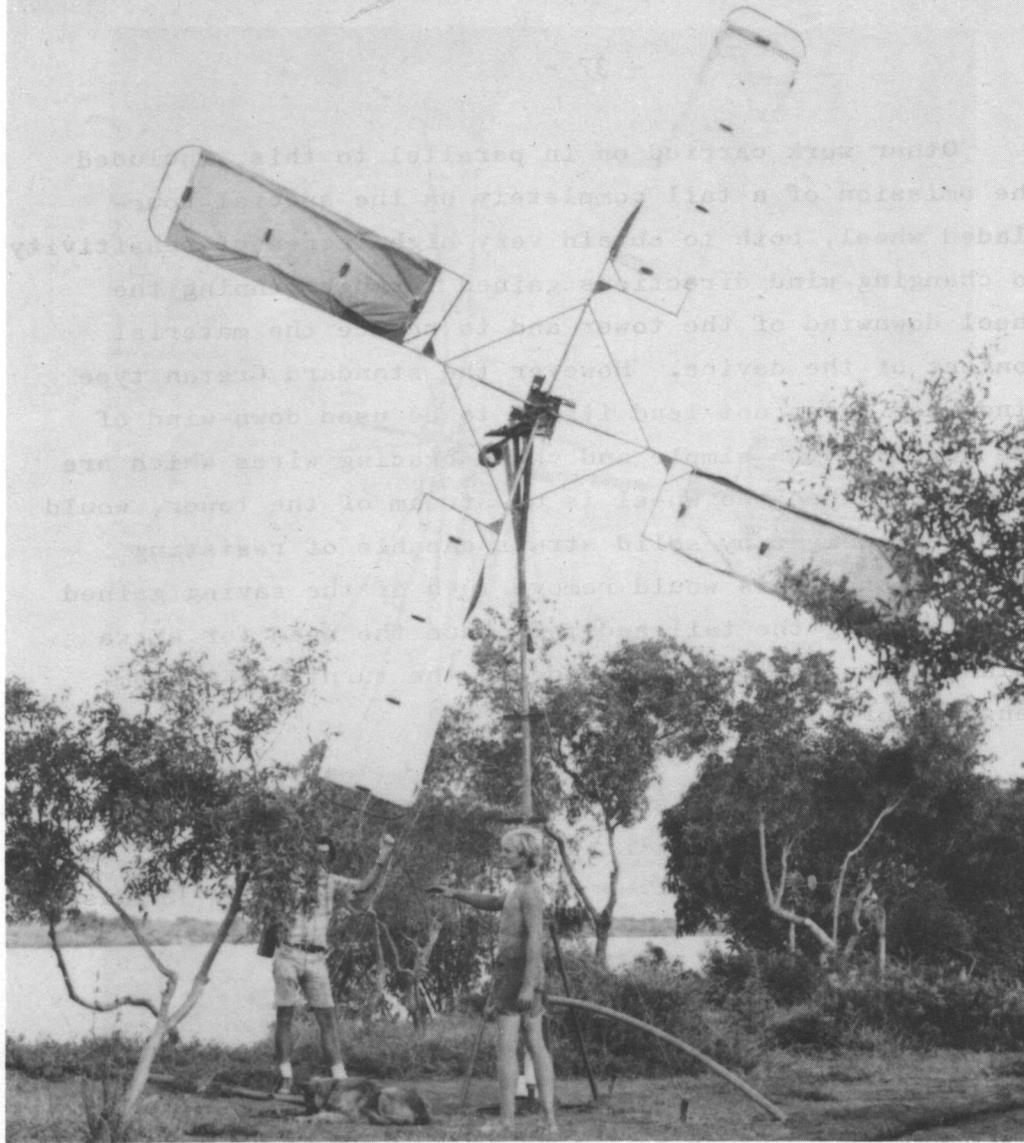


Fig 22. Tubular tower wind-mill.

of ordered construction materials were committed.

Provision of adequate pump-rod seal

The wooden plug with a hole for the pump rod proved suitable in situations where the delivery water runs downwards through a short length of plastic hose directly into distribution channels, but it precludes the delivery of water against heads of more than about 1ft (30cm) as in such situations significant quantities of water fountain out around the pump plunger and are wasted. As a result, certain areas of reasonable soil to the south of the mission that offer potential future plots for irrigation could not be used as any wind-mills supplying them would need to lift water through a static head of some 6ft (2m) with an additional substantial dynamic head due to the need for delivery through some 50 to 100 yds (m) of pipe.

Commercially manufactured seals were available from the pump manufacturer, but are relatively expensive and possibly have excessive friction as they are designed to withstand much greater delivery heads than are ever experienced or needed for this project. Therefore two alternative sealing devices were improvised from available materials (see Fig 23). The first is a gland-packing utilising a short length of compressed rubber hose as a seal. This has the advantage of being adjustable to cater for increasing leakage after wear takes place. The second system depends on shaped washers; a leather cup washer with an aluminium backing washer, which offer less friction than a packing as the water pressure itself presses the sealing edge against the plunger shaft. Both appeared to work reasonably well, at least for the short term of the author's presence, but the packing appeared to be more leakproof than the cup washer. Further developments that might be considered to overcome this problem are outlined in the section on recommendations.

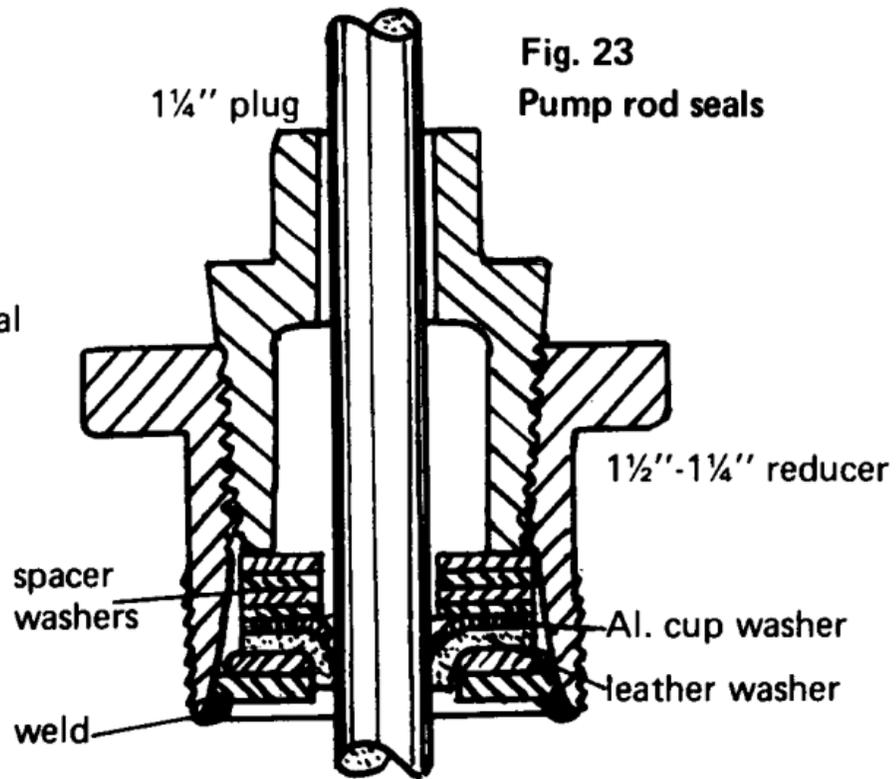
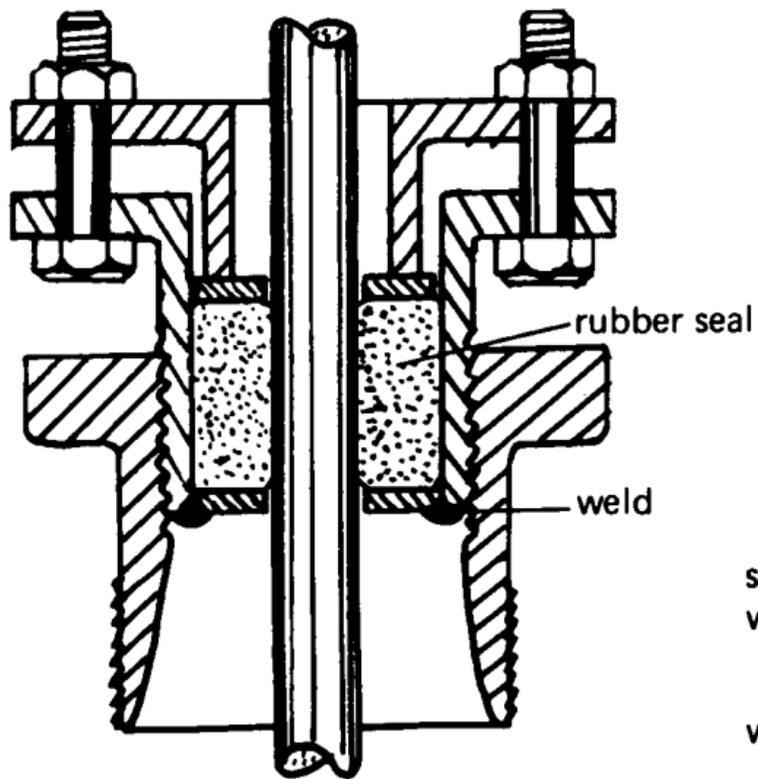


Fig. 23
Pump rod seals

Fig 23. Alternative pump rod seals.

Methods for reducing costs

As wind-mill systems intended as development aid depend for their attractiveness on achieving a long life with low-running costs (i.e. high reliability), any reductions which conflict with these requirements could be counter-productive. Therefore it is the author's opinion that the best means for achieving "cost reduction" is to improve performance, that is although the capital cost of the system may even increase, the aim will be to minimise the cost per gallon of water lifted. Any improvement which produces an increase in cost may be justified if it produces a proportionately greater increase in water output and conversely any cost saving reductions must be questioned if they can cause reductions in water output through either reduced running performance or reduced reliability/life. A further important consideration with metal wind-mill structures is the fatigue strength of various components; although an item may be quite adequately designed to withstand the loadings over relatively few cycles of operation, a wind-mill must withstand many years of operation if it is to be viable and should therefore have exceptional reserves of strength to withstand metal-fatigue. To emphasise this point; a reliable commercial vehicle is considered to have performed well if it runs 500,000 miles between show-room and scrap-yard, that is just under 17,000 hours at an average of 30 mph. This is the equivalent of $4\frac{1}{2}$ years of continuous operation for a wind-mill, which is a rather short period at least compared with life times of commercially manufactures water-lifting wind-mills, which are normally of the order of more than 10 years without major repairs.

These points are made because the author feels that small savings in capital cost that degrade the structural integrity of the design, as it has evolved, should generally be avoided. Having said that, a number of areas

where savings could be sought are pointed to by the cost breakdown (Appendix 2), which are discussed in some detail under the recommendations which follow.

Two practical attempts at cost reduction were attempted under the work programme. As the lattice tower did not lend itself to reduction of metal content, (mainly because the lateral members are needed to allow the towers to be climbed), an attempt was made to produce a tubular tower braced with guy ropes (Fig 22). This also lent itself well to the application of a simpler, small diameter, thrust bearing to support the tower-head. The design philosophy was to minimise the structural weight and cost of the tower relative to the dynamic parts of the system such as the wheel and transmission. The tubular tower was in fact very much quicker to build and was also cheaper in that it used less steel, but it proved very vulnerable if the guy ropes were not perfectly tensioned and eventually failed for this reason. Although braided steel rope was available for guying the tower, it could not be used as it is extremely likely to be removed by local people during the night, being very highly prized for making crocodile harpoons. Therefore, ordinary fencing wire was used which was prone to stretch; also constant vibration from gusts of wind loosened the anchorages. Therefore it was concluded that although this design approach might be viable in situations where adequate guying (probably from concrete anchorages) is possible, it was not an appropriate method in this situation. Further considerations weighing against the tubular tower were that it was rather more difficult and dangerous to climb than a lattice tower and that there was a considerable commitment in terms of materials on hand and ordered for the lattice towers, which were functionally quite satisfactory.

The other area where practical work aimed at cost reduction was completed was a study of redundant com-

ponents in the evolved design. It says much for the development skills of Messrs Swart and Pollock that there were few unnecessary components that had not already been eliminated. The main areas where savings can be effected is in increased ease of construction by the simplification of the head bearing already outlined together with the elimination of "balance weights" from the crank flanges. A number of towers were fitted with an unnecessary square top frame (a relic of the prototype tower design which, (copying those in Crete) was four-cornered); but these are no longer to be fitted now that the originally fabricated batch has been used up.

Consideration of alternative sails

The Dacron material, obtained free through the generosity of the manufacturers, has so far proved entirely satisfactory, (although a number of proposals for further development work on sail shapes and sizes are included in the recommendations). However, as conventional locally available fabrics had proved rather unsatisfactory in terms of durability, the author felt it was worth looking for alternatives in case either the supply of free Dacron were to dry up or if the system were to be tried elsewhere without the connection with the Dupont Corporation.

Therefore a pair of detachable aluminium sails were built, designed to be simply substituted for the existing design of Dacron sail on the standard wind-wheel (Fig 24). The sails needed to be removable to allow the same facility for adjusting the wind-mill to cope with different wind strengths. They were clipped to the wind-wheel at the front and were secured via polypropylene rope and rubber loops at the trailing edge and could readily be removed or fixed in place. The aluminium used was obtained by flattening some surplus aluminium roof cappings. This kind of material should be readily available and

cheaper than Dacron in most areas. It would also be very much more durable than any locally available textile materials. In addition, we found that provided the aluminium sails were mounted correctly (to avoid too shallow an angle of attack) the two aluminium blades provided about the same water pumping output in a given wind as three Dacron sails (Appendix 5). Lack of time prevented further experiments with larger numbers of aluminium blades. This work is of primary interest for any applications of the Omo windmill design in other areas, in which case further development of the aluminium (or perhaps wood or galvanised sheet steel) blades would be justifiable.

Method for testing wind-mills

The results of the testing system that was evolved proved how unreliable subjective impressions based on general observation of performance can be; it is very difficult to judge water delivery simply by looking at the appearance of the jet of water being produced.

Because the wind very rarely blows steadily for more than a few seconds, but tends to gust, it was not practicable to try and build a dynamometer to measure the shaft power output of a wind-mill (which would of course vary continuously with the wind). Also, it is not so much the shaft output, but the volume of water pumped in a given situation by the system as a whole that is of interest.

Therefore it was decided to bypass the problem of obtaining "instantaneous" values of power output to relate to wind-speed by measuring average values over short periods. This could readily be done by measuring the time taken to fill a 45 gallon oil barrel while simultaneously noting the wind-run over the same period, measured by the cup anemometer that was available for

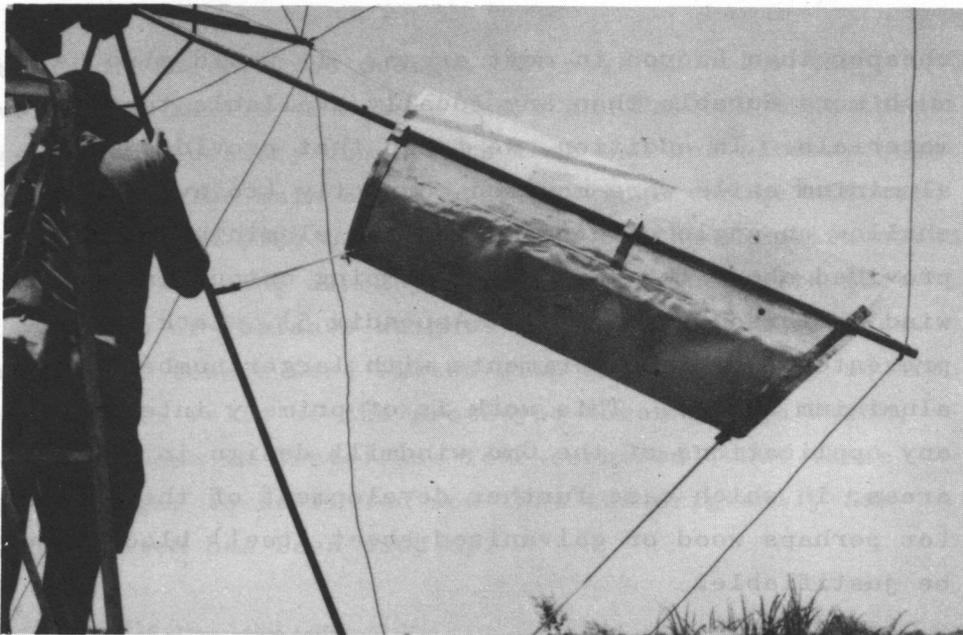


Fig 24. Windmill with experimental clip-on metal sails, beaten out of aluminium roof cappings.

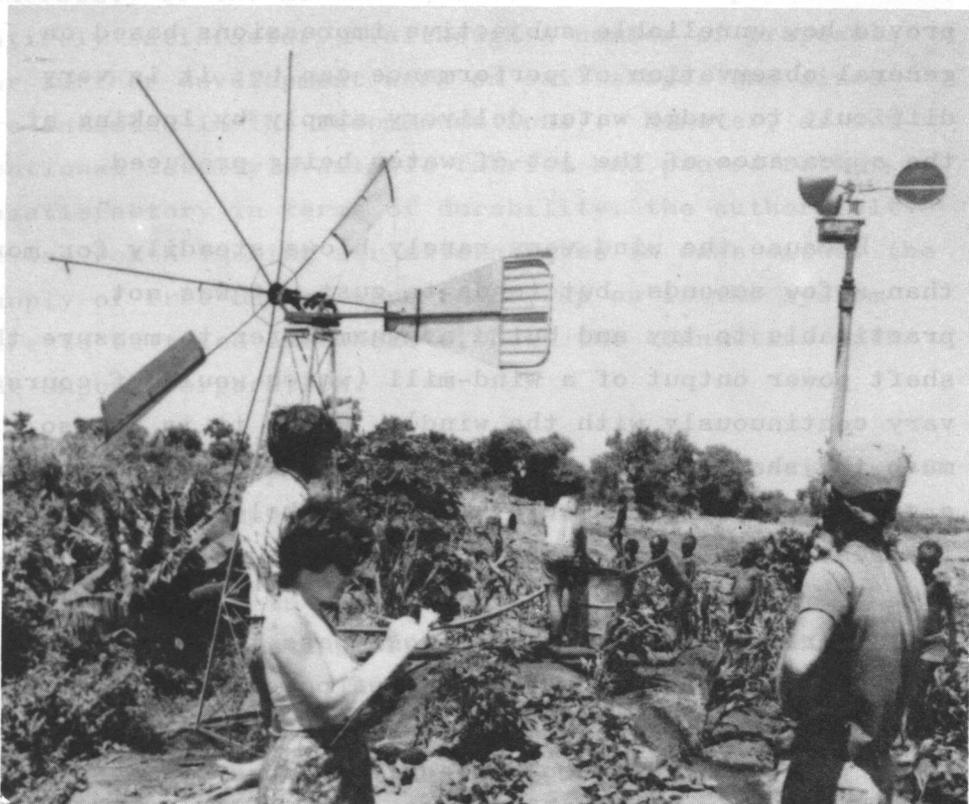


Fig 25. Windmill testing by filling a 45 gallon barrel (metal blades being evaluated).

the weather station (Fig 25). (A hand held wind-speed indicator was borrowed from the Missionary Aviation Fellowship, which gave instantaneous wind-readings, but this only served to show how variable the wind-conditions are, with the indicator marker continuously weaving up and down its scale).

The wind run (automatically integrated by the anemometer) divided by the time taken to pump 45 gallons gave the average wind-speed during the test, and the volume of water (45 gallons) divided by the time taken gives the average pumping rate. Hence values of performance in terms of water pumped in different wind-speeds were obtained for a number of permutations and combinations of wind-wheel size and numbers of sails, (see Appendix 5) From the knowledge of the volume of water pumped, the useful power output of the wind-mill can be computed by obtaining the total (manometric) head across the pump (this is the static head plus a dynamic head, the latter being estimated from standard tables) and multiplying by the weight of water pumped. By using appropriate units a dimensionless ratio, called the performance coefficient (see Appendix 3) can eventually be arrived at which provides a ready comparison for the efficiency of a wind-mill at converting wind energy into pumped water. This of course is efficiency in the technical sense; in the end the cost must also be considered and may make a technically inferior wind-mill have the economic edge over a more sophisticated technical design.

This testing system has the advantage of being simple to carry out and only requires a standard integrating cup-anemometer plus a 45 gallon (or other known volume) container. But it does pose problems of obtaining performance figures in very low winds, as, if the wind-wheel should stop during a test, the test becomes void because the anemometer usually continued to record wind-run while the wind-mill is stationary. Also, as low-

wind tests take the longest there is a high chance of a lull in the wind during such a test. Therefore it may be justifiable to modify testing procedure as outlined under the recommendations in order to obtain results at low wind-speeds more readily. This is quite important, as one of the main problem areas is to obtain the best possible performance in low winds from wind-mills.

Operational problems

The problem of obtaining more irrigation land for non-land-owning potential mill-owners is being tackled by the project organisers. One way of helping towards this is to try and ensure that existing mill users achieve successful crop yields, which will serve to generate even greater interest from non-users. The use of a suitable pump-rod seal may permit water to be lifted to a higher area to the south of the mission which is suitable for cultivation and will therefore open up a new area of "no man's land" and also wind-mills are now being installed in areas further from the mission where they may well attract further interest.

Poor water distribution and failure to rotate crops is being tackled intensively by Mr Larry McAuley, who is spending some six months at Omo Station and who has learnt sufficient of the Geleb language to communicate in little more than a month and who seemed to have established an effective rapport with the mill-owners. This of course continues the efforts along similar lines by the Rev Bob Swart who also of course speaks the local language with fluency and has run a continuous educational effort through discussions and through the provision of tape-players with cassettes to reinforce his teachings (Fig 26).

The author's wife, who accompanied him during the

project, conducted a series of interviews with mill-owners (using the good offices of the Rev Bob Swart as an interpreter) (Fig 27). This helped identify a number of cultural and social difficulties that had not previously been so clearly apparent. An outline of the findings from these interviews is included in Appendix 4 and it is suggested that occasional interviews might be organised from time to time in order to obtain a valuable feed-back from the mill users, both to identify new problems and to evaluate the effectiveness of attempts at solutions.

Although the author's prime task is to consider technical aspects of this project, the social and cultural side of applying this technology may be more critical in effecting the success of it than seeking technical perfection, and it also overlaps into the realm of the choice of technical approach. Therefore it is concluded that some of the more significant findings in this field are an important component of this report so far as understanding the complete perspective of the project is concerned.

5. CONCLUSIONS AND RECOMMENDATIONS

Some of the following conclusions became obvious during the course of the work programme and are already in the process of implementation. But for completeness these are included together with some ideas for further development which could be tested and introduced when the opportunity permits.

Wind-mill modifications

1. Increase wind-wheel size to 14ft (4.25m) diameter to improve starting and pumping performance. Further increases up to 20ft(6m)diameter might be tried, but accompanying increases in tower height will be needed, (such as indicated in Fig 28). (20ft diameter gives four times the power of a 10ft diameter mill).
2. If 14ft diameter (or larger) wind-wheels are used, it should be possible to build them with only six arms rather than eight and still achieve sufficient performance, so little (if any) extra material will be needed.
3. Further small gains in starting torque might be obtained by extending the inner end of the sails nearer to the wheel hub, (see Fig 29).
4. Starting performance might be slightly improved by sheeting the outer trailing edge of each sail less tightly so as to allow it to take up a steeper "angle of attack". Tests will be needed to check this in case it causes excessive sail flapping in higher winds.
5. The induced drag of the tail could be increased further by increasing its aspect ratio, (i.e. making it taller and narrower - see Fig 30). This would improve directional stability at no extra cost and permit a lighter tail on a longer boom to be used. Another improvement would be a swallow-tail arrangement (Fig 30) which should

be more sensitive to small changes in wind direction. Aluminium roof cappings, available at Omo, would be a suitable construction material for either of these types of tail.

6. A wire loop with a handle on the end of it could be attached to the tail to allow the wind-wheel to be turned out of the wind from ground level.
7. If directional stability problems persist, a wind-mill could be modified as shown in Fig 31 so as to operate down-wind of the tower. This would eliminate the need for a tail, but the other additions shown would be needed.
8. Initial tests indicated that a double-acting pump produces twice as much water as a single-acting one. Therefore a single-acting pump should be converted as indicated in Fig 32. The connecting rod will need stiffening to prevent it buckling on the down-stroke; a possible way of doing this is shown in Fig 33. If it proves difficult to convert single-acting pumps, it appears justifiable to use two single-acting pumps per wind-mill instead, as on the test installation.
9. Tests should be conducted to determine the best stroke when using either bigger wheel diameters or double-acting pumps. It is likely that a longer stroke could be used which would produce still higher pumping rates. The crank-shaft, bearings and wheel might have to be raised slightly to provide sufficient clearance between the pump rod and frame. These tests could be conducted either by making up several crank-shafts of different throws, or by making an adjustable stroke crankshaft such as that suggested in Fig 34.
10. An alternative way of fabricating crankshafts is indicated in Fig 35. The author is grateful to Marcus

Sherman of New Alchemy Institute for suggesting this means of obtaining correct alignment; apparently this is a method used in Greece. This would allow crankshafts to be made at Omo instead of at Ghimeera.

11. Circular or hollow bar (thick-walled pipe) would be more suitable for shaft material than the hexagon bar previously used.
12. The balance weights added to crank-shaft webs are not necessary and could be left off in future.
13. Sealed metal ball-races seem satisfactory while free stocks last, but olive wood bearings appear equally good and would be a better choice if ball-bearings had to be bought, being cheaper. Fig 36 illustrates methods for the possible controlled lubrication of wooden bearings which would be worth testing over an extended period.
14. The flanged-wheel type of tower head bearing should be discontinued. Roller bearings made from bits of pipe are less difficult to build, no more expensive and offer much less friction. Future bearings should use thicker-walled pipe for rollers and three rollers would probably be better than four to prevent wobbles due to inaccuracies of alignment. Alternatively plain metal-to-metal contact is cheaper and no worse than the flanged-wheel arrangement.
15. Home-made or commercially manufactured pump-rod seals should be used if lifting water against heads of more than about 5ft; Fig 23 shows the two home-made types tested during the work programme. A few of each should be made and tested to establish which is easiest to make and how well they perform. Alternatively, the modification shown in Fig 37 would be useful for low lift situations and might be generally introduced with all future wind-mills. It will require some modifications

to the connecting rod arrangement, and should be tested before being generally applied.

16. Major cost savings might be possible in the suction line and float assembly. The following might be tried: reducing the length of suction hose by up to 50% in some cases; trying $1\frac{1}{4}$ in diameter instead of $1\frac{1}{2}$ in diameter suction hose (if it is available from Addis Ababa) - although to avoid increased friction losses the smaller pipe should only be used in shorter lengths than at present; a smaller foot-valve, if available, would allow the use of a smaller (and cheaper) styrafoam float. The foot valve might be supported from a steel frame lying on the bed of the river, instead of from a float (such as in Fig 38), which should be cheaper.

Testing procedure

1. It is recommended that a standardised wind-mill testing procedure, such as that described earlier in this report, be instituted to evaluate any modifications to the wind-mills.
2. Smaller containers than 45 Imp. Gallon drums might usefully be used for low wind tests as these would shorten the test period and reduce the chance of the wind-mill stopping during the test.
3. The following information should be recorded during a complete test:-
 - 1) diameter of wind-wheel
 - 2) number of sails
 - 3) time for test
 - 4) volume of water pumped during test (size of container filled)
 - 5) wind-run measured during test
 - 6) static head (height vertically from river level to

delivery hose outlet)

7) approximate length of suction + delivery hose and diameter of hose

8) special modifications or conditions

Items 6 and 7 may be omitted to obtain simpler comparative results on the same wind-mill, providing these tests take place without any change in river level or delivery hose outlet level.

The Intermediate Technology Development Group can undertake to evaluate and comment on any such test results taken in future, if required.

Meteorological station

1. The anemometer should ideally be located within the mission compound on or near the river bank, as clear of the trees as possible. Although this is not completely in accordance with weather station specifications, it is consistent with the typical positioning of most wind-mills and should allow wind data to be related to wind-mill performance.
2. The rest of the weather recording equipment would be better located at the south-west corner of the mission compound, where it will be unlikely to be affected by river seepage or flooding and will also be clear of shading by trees.
3. The system adopted for taking readings three times every 24 hours at 0700, 1300 and 1900 hours seems quite adequate for obtaining a meaningful record of the monthly variations in wind régime. It would provide a valuable extra information input if readings could be taken hourly, or even two hourly, from 0700 to about 1600 on about one day each month to gain some idea of hourly wind variations; a "typical" day should be chosen for this. Again, ITDG

would be prepared to evaluate the wind régime further with particular reference to wind-mill operation, after about one complete year's figures are available.

Use of Omo wind-mills in other places

1. These wind-mills are only really suitable for use in locations where there can be almost constant supervision when they are in operation, (i.e. for irrigation), so that sails can be removed or added if the wind changes.
2. They are comparatively low-powered devices so they are not suitable for lifting water through heights much greater than 30 to 40ft (10 or 12m) and they would in any case need different pumping arrangements to those used at Omo if working with suction lifts greater than about 20ft (6m). It would be possible to use these mills for even higher lifts, but volumes of water pumped would be quite small.
3. Care should be taken to relate the wind-regime at any other location with that at Omo Station before any conclusion as to wind-mill performance can be made.
4. The equipment required to build this kind of wind-mill (as used at Omo) consists of an electric arc-welding set, a light vertical drilling stand with a heavy-duty electric drill, a wood-lathe, plus a work-bench and hand tools. Plumber's pipe thread cutters are also necessary for assembling the inlet and outlet pipes.

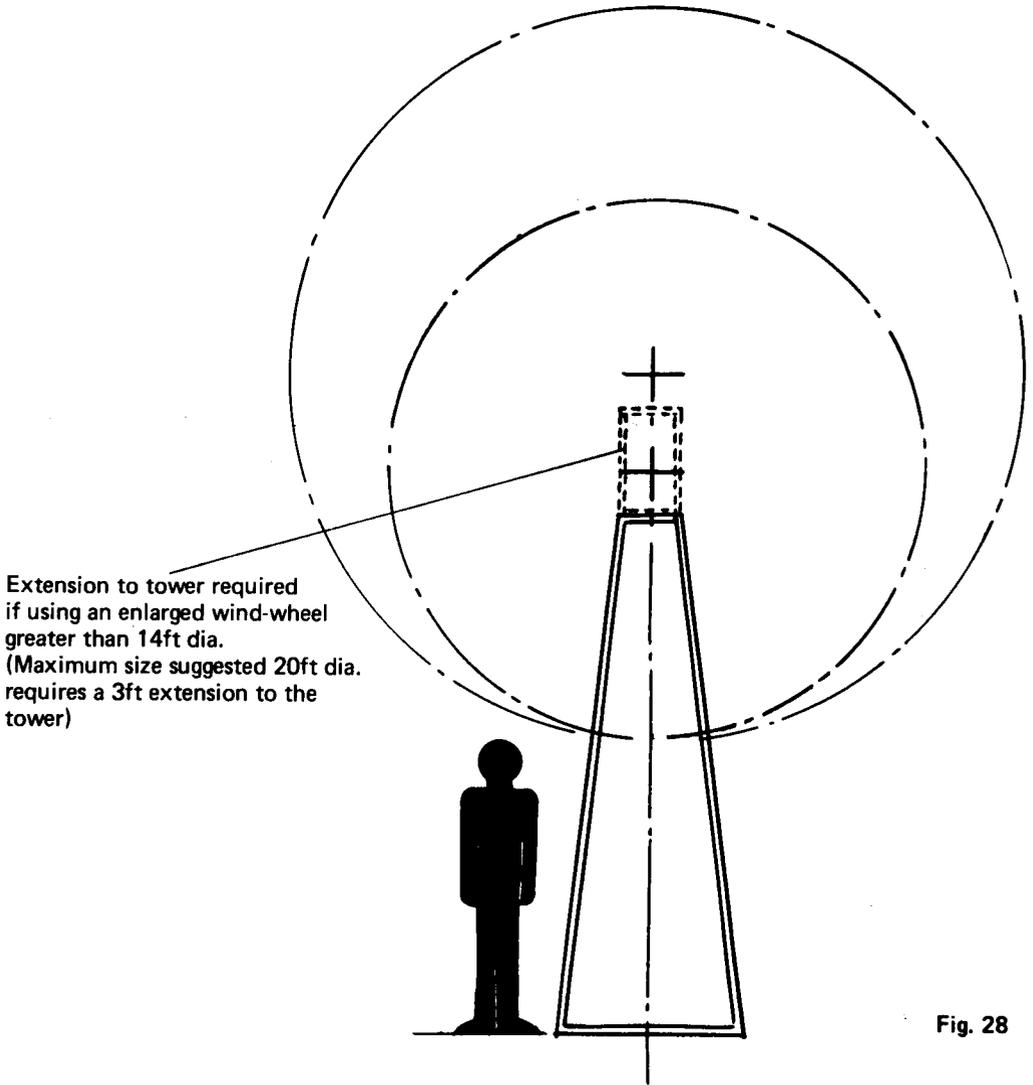


Fig. 28

Recommended six sail rotor with sails extended as close to the hub as possible. Existing sail as used on smaller wind-wheels is shown dotted.

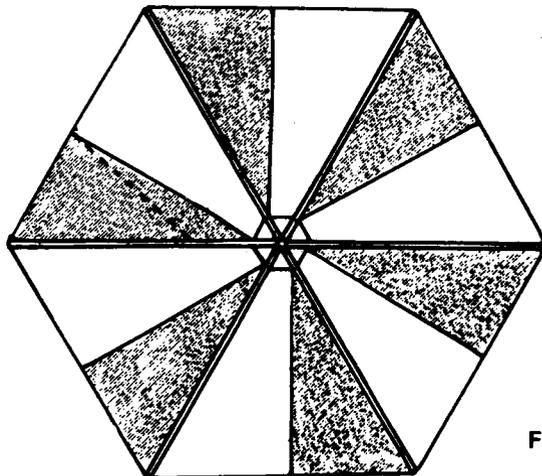
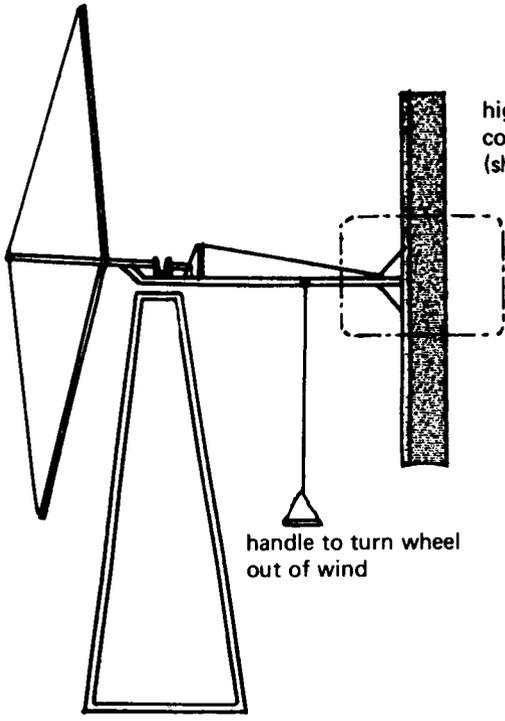


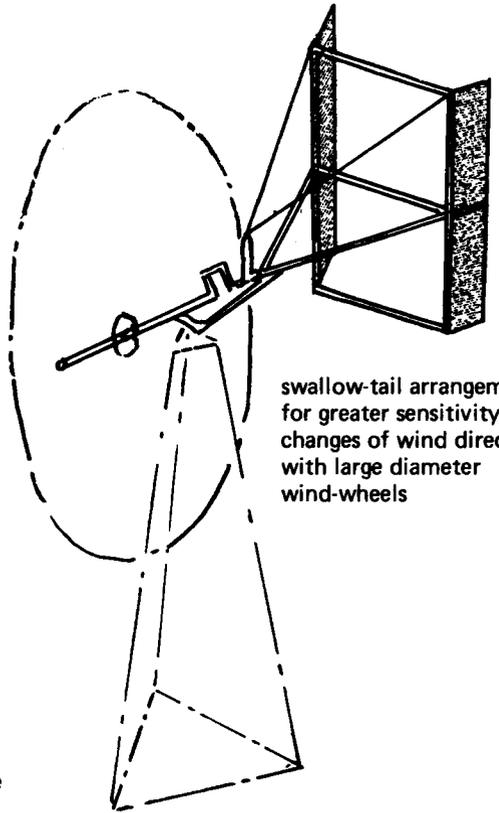
Fig. 29



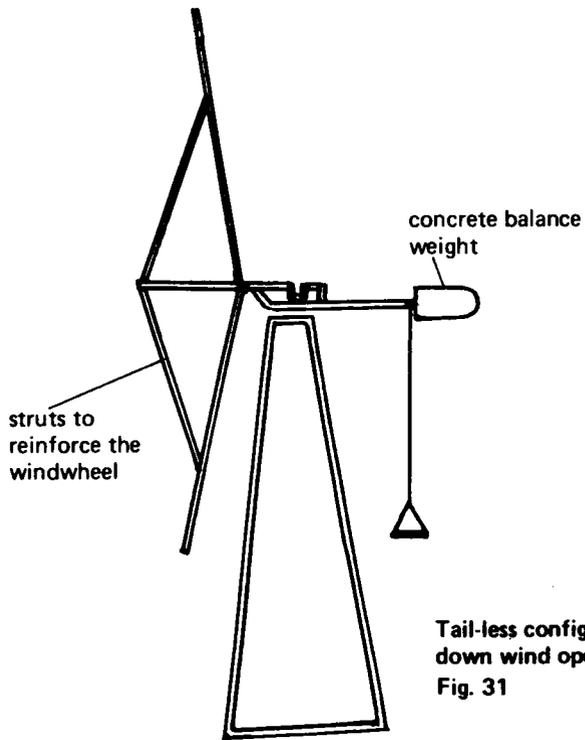
high aspect ratio tail compared with standard tail (shown chain dotted)

handle to turn wheel out of wind

High aspect ratio tails
Fig. 30



swallow-tail arrangement for greater sensitivity to changes of wind direction with large diameter wind-wheels



struts to reinforce the windwheel

concrete balance weight

Tail-less configuration for down wind operation
Fig. 31

Fig. 32
Double acting pump
conversion

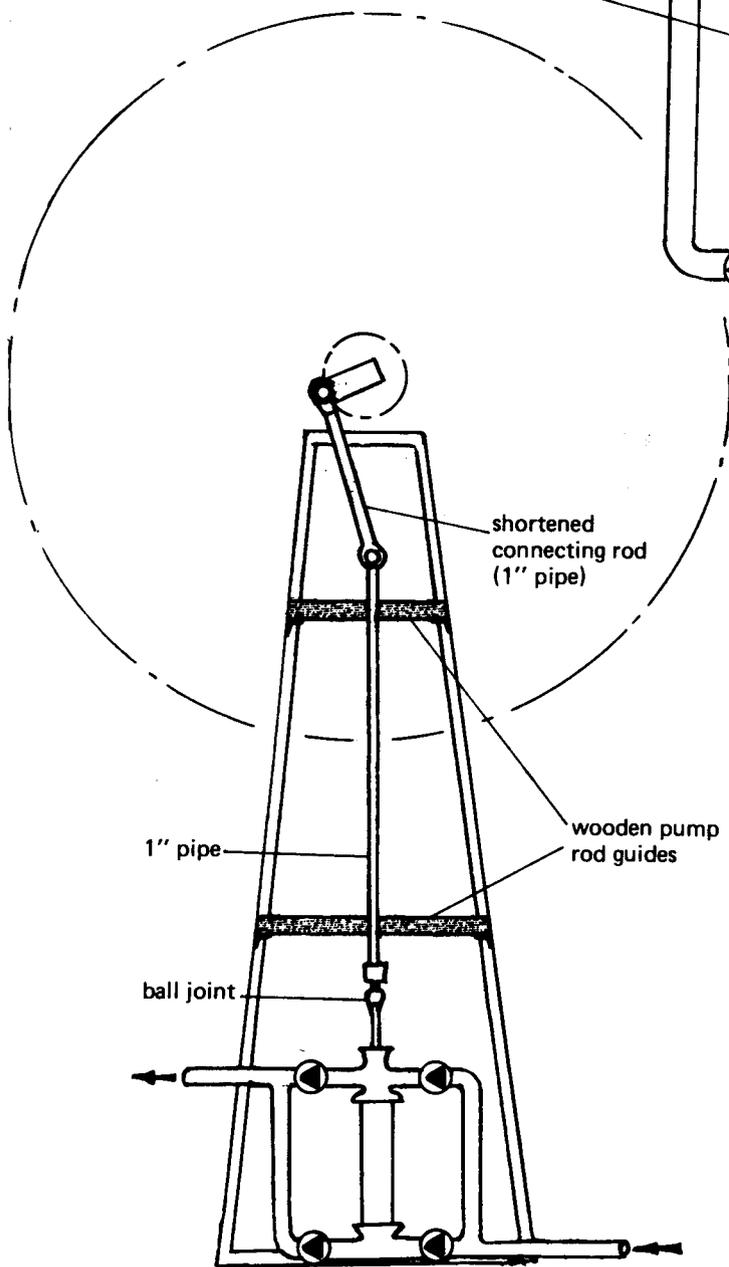
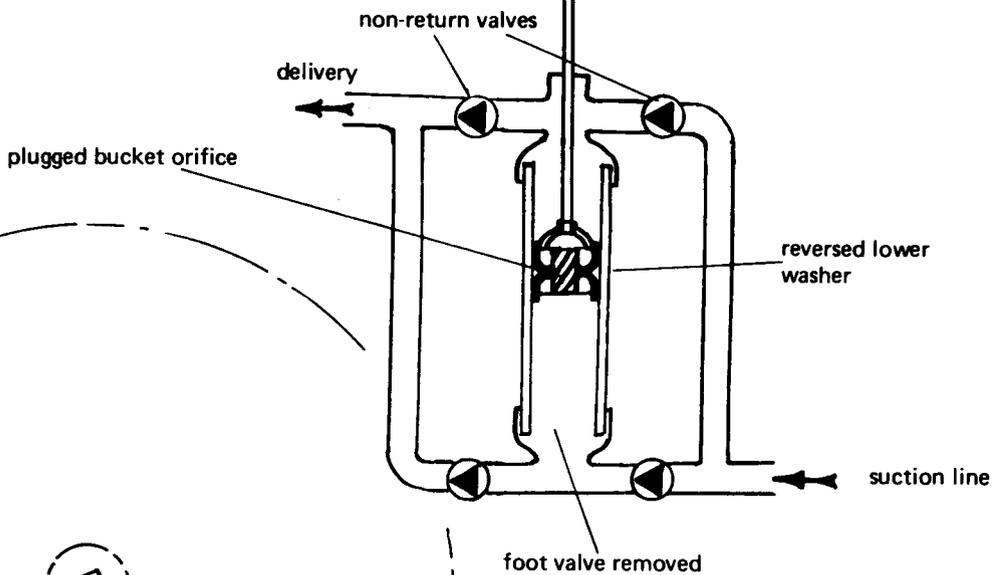


Fig. 33
Stiffened transmission for
double-acting pump

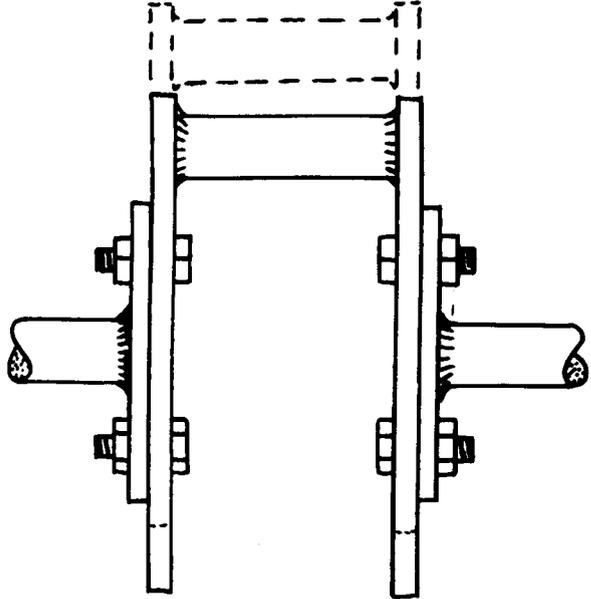


Fig. 34 Adjustable throw crank

Fig. 35 Method for fabricating crank to ensure correct shaft alignment after welding

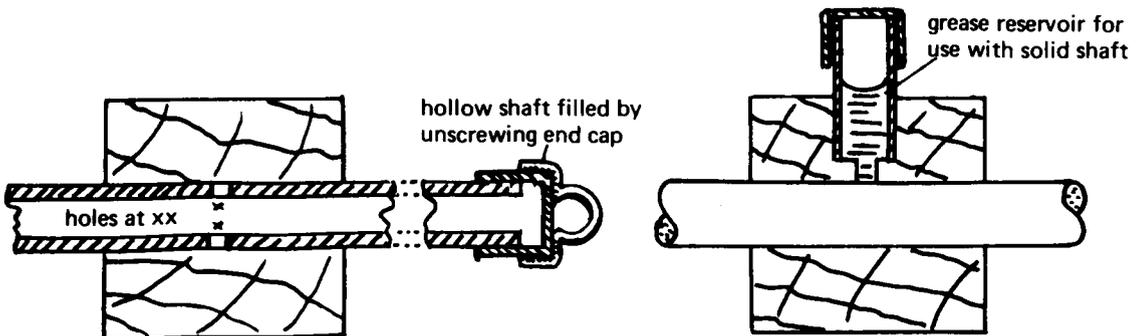
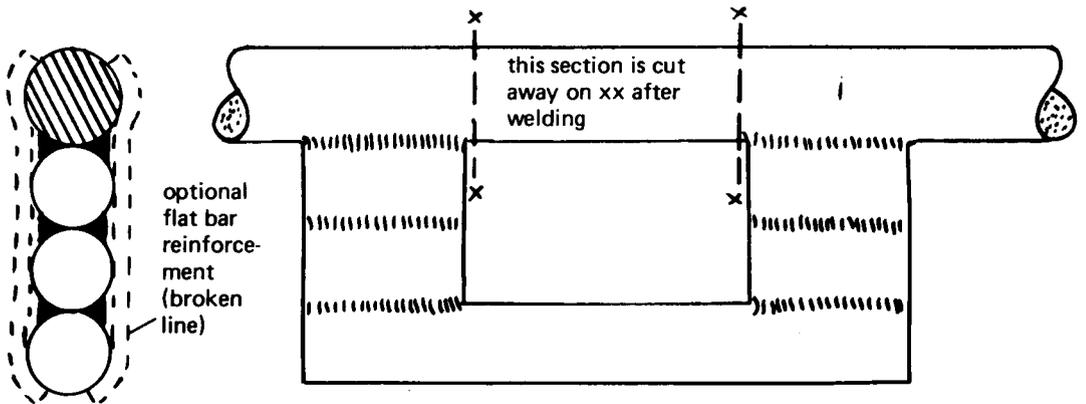


Fig. 36 Grease lubrication systems for wooden bearings

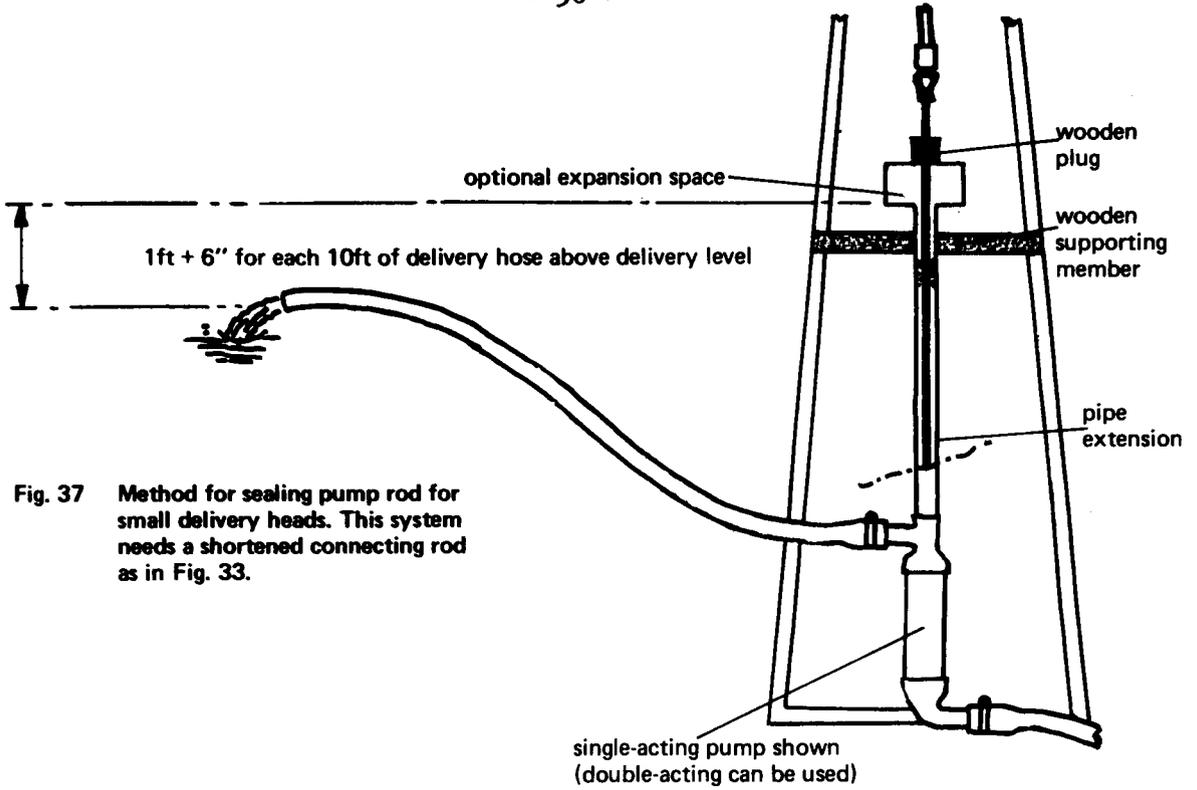


Fig. 37 Method for sealing pump rod for small delivery heads. This system needs a shortened connecting rod as in Fig. 33.

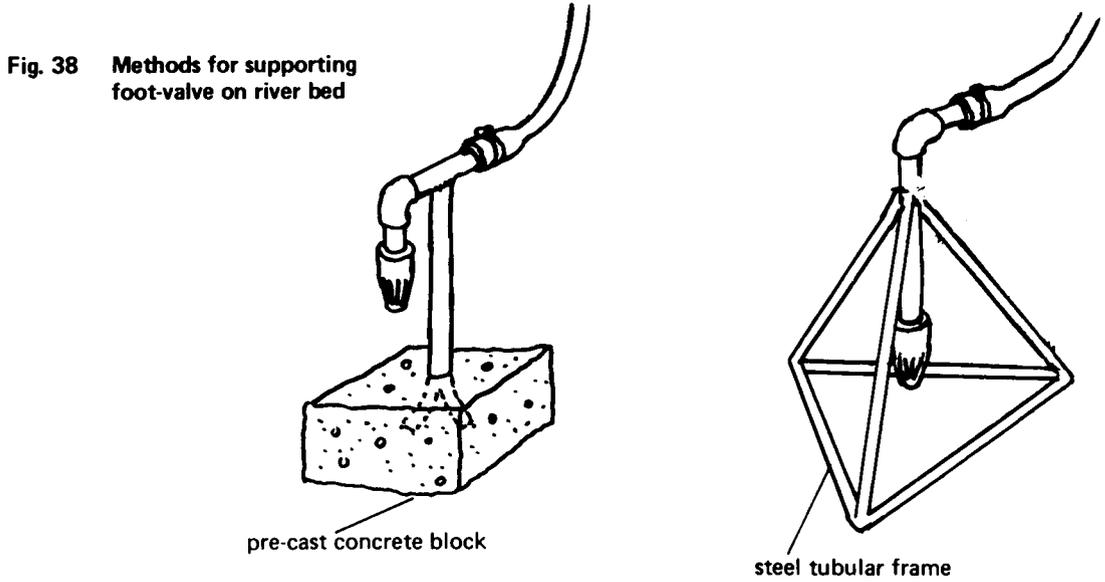


Fig. 38 Methods for supporting foot-valve on river bed

1. Wind-mills in use by Geleb farmers.

1	April 1974	Dempster (imported from USA)
2	June 1974	10ft sail
3	June 1974	10ft sail (removed July 1975)
4	June 1974	10ft sail
5	August 1974	10ft sail (modified to 14ft diameter in July 1975)
6	January 1975	Savonius rotor
7	January 1975	10ft sail
8	March 1975	10ft sail
9	March 1975	10ft sail
10	March 1975	Dempster
11	March 1975	10ft sail
12	April 1975	10ft sail
13	April 1975	10ft sail
14	April 1975	Savonius rotor
15	April 1975	Savonius rotor
16	May 1975	Savonius rotor
17	May 1975	11ft sail
18	June 1975	11ft sail
19	July 1975	11ft sail
20	August 1975	11ft sail

2. Wind-mills in use in mission compound (commissioning dates not available)

- 2 x Dempster (for irrigation and water supply)
- 2 x 10ft sail (for instructional purposes at farmers' classes)
- 1 x Savonius (for medical dresser's family water supply and garden)
- 3 x various (for experimental work)

3. Completed and awaiting commissioning

11 x 11ft sail (most were due to be modified to
14ft diameter)

4. Materials on hand or on order

For approximately 20 further wind-mills.

APPENDIX 2 : Cost breakdown on wind-mills

There is no completely precise means of estimating the cost of wind-mills as there are a number of different variations in the design, materials are cut with varying efficiencies in terms of minimising off-cuts, and due to inflation and/or different supply sources, various materials vary in price depending on when and where they were ordered. In addition, certain components were manufactured at Ghimeera and the cost of these was unavailable at Omo, so an estimate for these items has been made. Once a standard design is finalised more precise cost estimates will be possible, but nevertheless, the figures arrived at either from mission accounts giving actual expenditure or from a breakdown of a mill by components gives reasonably consistent results amounting to around Ethiopian \$700 per mill (note: Eth \$2.07 = US \$1.00) for materials plus a nominal sum to cover indirect expenditure and capital investments.

1. Estimate for OXFAM funding Eth \$700 per mill (Ca. £160)
2. Cost derived from "Food for Wind" accounts 1974 and 1975.

Total expenditure 1974 accounts*	Eth \$ 20,899
Total expenditure 1975 accounts*	\$ 12,950
	\$ 33,849

Of which indirect expenditure on capital equipment (tools, etc.), cassette recorders, etc., accounted for.. \$ 8,664

Leaving direct expenditure on materials \$ 25,185

* (no labour costs included and excluding costs of pumps and heads produced under different budget at Ghimeera for about \$80 per pump plus \$40 per head).

Therefore ... mills erected (various types but excl. Dempsters)	24
mills completed and awaiting commissioning	11
<u>materials paid for and not yet used for approx.</u>	<u>15</u>
Total mills paid for under this budget	50

Hence ... cost per mill $\frac{\$25,185}{50}$ plus \$120 for head & pump

gives total material cost per mill of \$623.70

If capital expenditure of \$8,664 is also included for the 50 mills, we arrive at

material costs + capital expenses \$796.98

It should additionally be noted that various components were obtained free or at a special discount (sail material free, pumps at 50% discount) but against this high transport costs are involved from Addis Ababa to Omo Station which probably more than cancel out the free or cheap items. The 50 mills include such experimental units as the Savonius rotors, which probably cost more than the sail wind-mills. Because labour is not specially paid for on this project, it has not been costed and neither on the other hand is there any credit included for the nominal payments of \$5.00 per year paid by Geleb farmers.

3. Breakdown of cost by component for 11ft sail wind-mill

Steel costs were derived by weight of actual components at the rate Eth \$1.50 per kg + \$0.35 for transport (i.e. not

including any wastage from off-cuts). Total weight of steel components 113 kg.

steel	₪ 209.05	foot valve	₪ 12.85
pump	₪ 80.00	sail fixings	₪ 7.00
paint	₪ 10.00	float drum	₪ 10.00
nuts & bolts	₪ 4.15	welding rods	₪ 4.00
sails	₪ 0.00	pipe fittings	₪ 9.00
pvc suction pipe	₪ 100.00	electricity	₪ 10.00
Styrofoam float	₪ 12.50	head assembly	₪ 40.00
		TOTAL :-	₪508.55
		plus tax 7%	₪ 35.60
		NET TOTAL MATERIALS	<u>₪544.15</u>

This of course allows for no wastage (off-cuts) and the cost arrived at under paragraph 2 above from mission accounts allows for experimentation and trial and error (including the Savonius Rotor wind-mills which probably cost rather more in terms of materials). It is also based on steel prices applicable in Addis Ababa in 1974 when materials were last ordered. Therefore, it is likely that the figure of ₪700 will probably barely cover material costs per wind-mill in future material purchases.

4. Relative cost of importing factory-built Dempster wind-mills

These cost around Eth ₪2,000 each, landed at Omo station and would probably cost at least 10 to 15% more at the time of writing following steel and transport cost increases. The modified sail wind-mills are capable of lifting similar or greater quantities of water than the Dempsters and do not rely on imported spare parts or regular lubrication. The Dempster is one of the least expensive factory-built wind-mills available; a South-

ern Cross 21ft wind-mill (from Australia), which is much bigger than the 8ft diameter Dempster of course, was quoted at Eth \$19,000 landed at Addis Ababa in September 1975. It would of course pump much more than the little sail wind-mills, but probably not 27 times as much - this being their relative costs!

APPENDIX 3 : Some principles of wind energy conversion

1. Power from the wind

$$\text{Power } P = k.C_p.A.v^3$$

where: k is a constant dependent on the system of units being used

C_p is the Coefficient of Performance, which is a measure of the efficiency of energy conversion

A is the cross-section of air stream being used (area of wind-wheel)

V is the speed of the wind

If P is in horsepower, A in ft² and v in miles/hour, this becomes:-

$$P = 0.0000071 C_p A v^3$$

or if P is in kilowatts, with A in m² and v in m/s, it is:-

$$P = 0.00064 C_p A v^3$$

These formulae, which are commonly quoted in the literature on wind-power, assume that the air is at a density appropriate to sea level and 15°C. Higher altitudes and temperatures rarify the air and consequently cause a lower power output. For the purposes of the graphs which follow (Appendix 5) the effect of altitude and temperature has been ignored, implying therefore that the wind-mills are potentially slightly more efficient than might appear from the figures, if they were used at sea level under cooler conditions. Also, it is normal to take the entire disc area of the wind-wheel as being A in the formula,

but as rather small sails were used on the larger diameter wheels, the area swept by the sails has been taken. This has been applied for all wind-wheel sizes to achieve consistency for purposes of comparison.

2. Starting torque

A certain minimum torque (or twisting force on the wind-mill shaft) is needed to overcome the static friction in any wind-mill system and allow pumping to begin. The torque produced by the wind-wheel is a function of the tangential turning forces on each sail, the number of sails and the average radius (or leverage) that these forces act on the shaft from the tangential turning forces are approximately proportional to the square of the wind-speed.

Therefore, torque will be proportional to the radius of the wind-wheel and to the square of the wind-speed. The bigger the wind-wheel diameter, the lower the wind-speed needed for starting.

3. Power requirement for water lifting

The net power output of a water lifting wind-mill will move water at a rate such that the power output is directly proportional to the product of flow rate and the pressure difference across the pump (or resistance to flow).

The pressure difference across the pump is a combination of the static head of water being lifted, which is the vertical height from the surface of the river to the outlet of the discharge pipe, and frictional resistance to flow which is generally called the dynamic head. The dynamic head is a function of flow rate and the length, diameter and condition of the pipe system. The more water is pumped through a given system, the higher is

the frictional resistance to flow and the greater the dynamic head. An estimate of the dynamic head for the Omo wind-mills can be made from the following table which considers 100ft of $1\frac{1}{2}$ in and of $1\frac{1}{4}$ in diameter pipe (the two options discussed in the text). Friction or dynamic heads for other lengths can be estimated on a pro rata basis, i.e. 80ft of pipe would produce 0.8 times or 80% of the head that 100ft produces. An additional amount, say a nominal 25%, should be added to allow for the extra resistance caused by bends, the foot-valve and pump valves.

flow rate:	200	600	1000	1400	1800	imperial gallons/hr
<hr/>						
dynamic friction head in ft. water						
100ft $1\frac{1}{4}$ in pipe	0.6	4.5	11.0	20.0	33.0	
100ft $1\frac{1}{2}$ in pipe	0.3	1.8	4.8	9.0	14.0	

This indicates how shortening the suction line as advocated in the text could not only reduce costs but can also reduce the dynamic head thereby producing an increased flow. If smaller diameter pipe is used to save cost, then shortening it too is important to avoid unacceptable increases in head.

The total net power output of the system, as defined for the graphs in Appendix 5, consists of:-

$$P_{\text{hydraulic}} = K (h_{\text{static}} + h_{\text{dynamic}}) \times (\text{weight water/sec})$$

(where K is a suitable constant dependent on the units used)

4. Coefficient of Performance C_p

This has been defined for the purposes of Appendix 5 as:-

$$P_{\text{hydraulic}} = C_p \cdot P_{\text{wind}}$$

$$\text{i.e. } C_p = K \frac{(\text{Total head}) \times (\text{weight of water/second})}{(\text{Area of wind-wheel}) \times (\text{wind speed})^3}$$

where K is the appropriate conversion constant

In other words, C_p is taken as an overall system efficiency for the combined wind-mill and pump installation.

It can be shown that the maximum theoretical rate of wind energy conversion by a wind-mill is 59.3% of the total kinetic energy of the wind. Therefore the efficiency as a fraction of what is theoretically attainable will be rather better than the value of C_p by a factor of $1/0.593$ or 1.686. For example the value of C_p of 0.1 represents nearly 17% conversion of available wind kinetic energy.

APPENDIX 4**Interview with Geleb farmers**

I am indebted to my wife for collecting the material from which these notes have been condensed during a series of interviews with various Geleb farmers. We are also grateful to both the Rev Bob Swart and to Mr Thompson Gac, the mission medical dresser, for their services as interpreters.

1. Koriye

He is one of the original pioneers. Began with a hand-pump having admired Thompson Gac's clinic garden which was similarly irrigated. Then obtained first Dempster in April 1974 (Fig 4). Has grown cabbages, corn, peanuts and beans and now has a variety of fruiting trees including paw paw, mango, lime, guava, grapefruit, fig, banana and tangerine. Sells cabbages, limes and mangoes to police at Kelem. His wife and five children help with the work and also help maintain a traditional flood-land garden where he grows millet, maize, beans and tobacco. Eldest daughter generally looks after flock of sheep and goats. His one cow is in the care of a friend. He finds it a problem to look after both wind-mills and cattle and says this is a general problem for other mill-owners too. He has no land problem as he has the rights to the land he is farming, but he has suffered from theft of crops by what he calls "hyenas" (meaning other people).

Koriye, who is in his thirties, is very willing to try new ideas despite having had no education at all. He is talking of using a plough, which would be a radical change in this area where animals are never used in agriculture. He thinks solutions can be found to most of the problems faced by mill-owners; cattle can be left in the care of relatives or friends; he has fenced parts of his plantation to guard against theft. His crops are particularly vulnerable as he lives the other side of the river due to mosquitoes on the east bank;

he says he would move if he could build a mosquito-proof hut.

He says his family have not been hungry since he has worked with the wind-mill, and he had obtained five harvests up to August 1975.

2. Natakan

Koriye's Dempster provides more water than he can use, so he allows three other men to cultivate adjacent plots of his land. Two, who are not relations, pay a small rent to him, the third is his cousin, Natakan, who works his plot free. He grows maize, tomatoes and ground nuts, but no fruit trees and has had three harvests so far. First two were good but the latest spoiled by hyenas (not specified whether this was a euphemism or not) and water buck. He also cultivates flood land. Younger brother is responsible for his few cows, goats and sheep, but he occasionally leaves his cultivation in his wife's care for a few days to go and see how his animals are, particularly when they are grazing far away. He sees two advantages in cultivation; it ensures his family always has food and he claims it enables him to buy more cattle.

3. Lohkwar

He was the first to operate a sail wind-mill and also is the only wind-mill farmer to give up his mill. He spent two years at the mission school and started wind-mill farming much younger than the others, at the age of 20 (approximately). He had no land, but a cousin of Koriye (qv) gave him a plot to use for nothing. This plot proved to be difficult for him, in that it is a bit sandier than most and soaks up water quickly. At first Lohkwar and the owner of the land worked the plot together, but the owner soon lost interest and left Lohkwar to work it on his own. He grew ground nuts and

maize, but only got a small ground-nut crop and he allowed the maize to dry out and lost the lot. Although other farmers have worked equally difficult plots, Lohkwar was discouraged and tried to find another plot; he was offered one at an exorbitant rent. He left his difficult plot in the charge of a small boy and neglected it and then finally gave it up completely. He now has a job as a helper at the mission clinic, but says he would try wind-mill cultivation again if he could find a better plot of land. His wife cultivates a small plot of flood land, in the meantime, which yields one small annual crop of millet. They have no cattle, but own a few goats and sheep which his younger brother looks after.

4. Igogor

There are ten wind-mills on a single large plot of land about 1 mile downstream of the mission. The land belongs to Igogor, an older (probably late 40s) and more senior man than most of the other mill owners. His wind-mill installed in August 1974 was the first on the site and he has used it continuously except for a gap of one month when he once did not replant straight away after a harvest, but took his cattle to some distant grazing. He stays with his cattle when they are far away and delegates the wind-mill cultivation to one of his two wives, (his children are all very young in spite of his age). Men with mills on neighbouring plots help her with putting the sails on for watering when Igogor is away, but he always prepares the plots for planting. He has had five maize harvests and has also grown millet, sugar cane, peanuts, paw paws, sweet potatoes, guavas, mangoes, tobacco and water melons. He tried pigeon peas but they failed. He likes his mill and sewed up tears in the sails himself before getting the stronger Dacron sails. He is critical about the volume of water pumped by his mill (having seen the diesel pump at Rati on the EPID irrigation scheme). Therefore his mill was modified

as quickly as possible to the new 14ft diameter to improve its low wind performance. (The diesel scheme has several times been in serious trouble with engine failures and there is a continuous worry about fuel shortages - the wind-mill workshop has twice provided tools when the US Peace Corps worker in charge of the diesel irrigation scheme had inadequate facilities of his own to repair the engines; unfortunately the Gelebs do not appreciate the problems and expense of diesel engine maintenance in such remote areas).

Igogor, being enthusiastic about wind-mills, readily releases large areas of land he has rights to for other people to cultivate with wind-mills. He has had problems with soil depletion and insect pests due to his failure to rotate crops properly (he is now being helped to remedy these problems). But he claims his family are no longer hungry as they used to be at certain times of the year.

5. Korass

Unlike Igogor, Korass is poor and has no land rights. However a younger cousin, Natade, who has a suitable plot permitted him to cultivate it, without any payment. Korass obtained his mill in June 1974, and as he had no money, he paid for it by collecting firewood for the mission. The soil was poor at the first place he tried, so after a while the mill was moved a little way along the river bank. Again the soil was poor and the mill was moved a second time (one good reason for not needing permanent foundations!). Since then Korass has had two good maize harvests and one poor one. He has also grown soya beans, sweet potatoes, tomatoes, bananas and has young paw paw, lime and fig trees. His pigeon peas also failed. He also grows millet and tobacco on flood lands, and his wife grows beans. His wife helps him with the main plot. He has no cattle; only a few goats. He has a daughter approaching marriagable age and hopes for cattle from the family of whoever marries her.

Korass, like Lohkwar, is easily discouraged by crop failure and needs encouragement, but he does recognise the value of his wind-mill and claims that a man with a wind-mill who works well need never be hungry.

6. Achao

Achao is the mission's handy man (and he happens to be Korass's younger brother). He has had no schooling, but has worked closely with Bob Swart for several years and learns quickly, so he is well able to assemble and paint wind-mills and he can dismantle and over-haul the pumps. He also helps new mill owners and as explained earlier, recorded the special cassettes they got. He has no wind-mill of his own, preferring his regular handy-man job, but his wife grows flood-land crops. He has a few sheep and goats and is buying a cow by instalments from Bob Swart.

The graph on the right indicates the comparative pumping ability of various windmills of different diameters with different numbers of sails deployed. Also included are the results of tests on two and three-bladed Savonius Rotor windmills which demonstrate the poor performance of this type of device. The 16ft diameter mill driving twin pumps clearly out-performs everything else. The static head in all cases is quite low, being about 9 ft (2.75m). If these windmills were used for lifting water to a greater height, then the delivery would be proportionately less.

APPENDIX 5 Test results on wind-mills

X₁₆ (2 pumps)

1200

WATER LIFTED
(Imp.galls/hr)

1100

1000

900

800

700

600

500

400

300

200

100

SUMMARISED TEST RESULTS

(Heads all about 9ft)

1. The number of bars represents the number of sails deployed
2. The suffix gives wheel diameter in feet. Metal blades indicated.

X₁₆ (2 pumps)

*₁₄
*₁₄

^₁₄
/ ₁₄metal
^₁₄ ^₁₄
X₁₁ ^₁₄
X₁₁ ^₁₄
^₁₄
^₁₆

X₁₆ X₁₆

^₁₆

/ ₁₄metal
/ ₁₄metal

/ ₁₄ / ₁₁

^₁₆

⊗ triple savonius

⊗ double savonius

⊗ triple savonius

⊗ double savonius

*₁₄

X₁₄ X₁₄

*₁₄ *₁₄ *₁₄ *₁₄

^₁₄

*₁₄

X₁₆ *₁₆

^₁₄

*₁₆

X₁₆ X₁₄

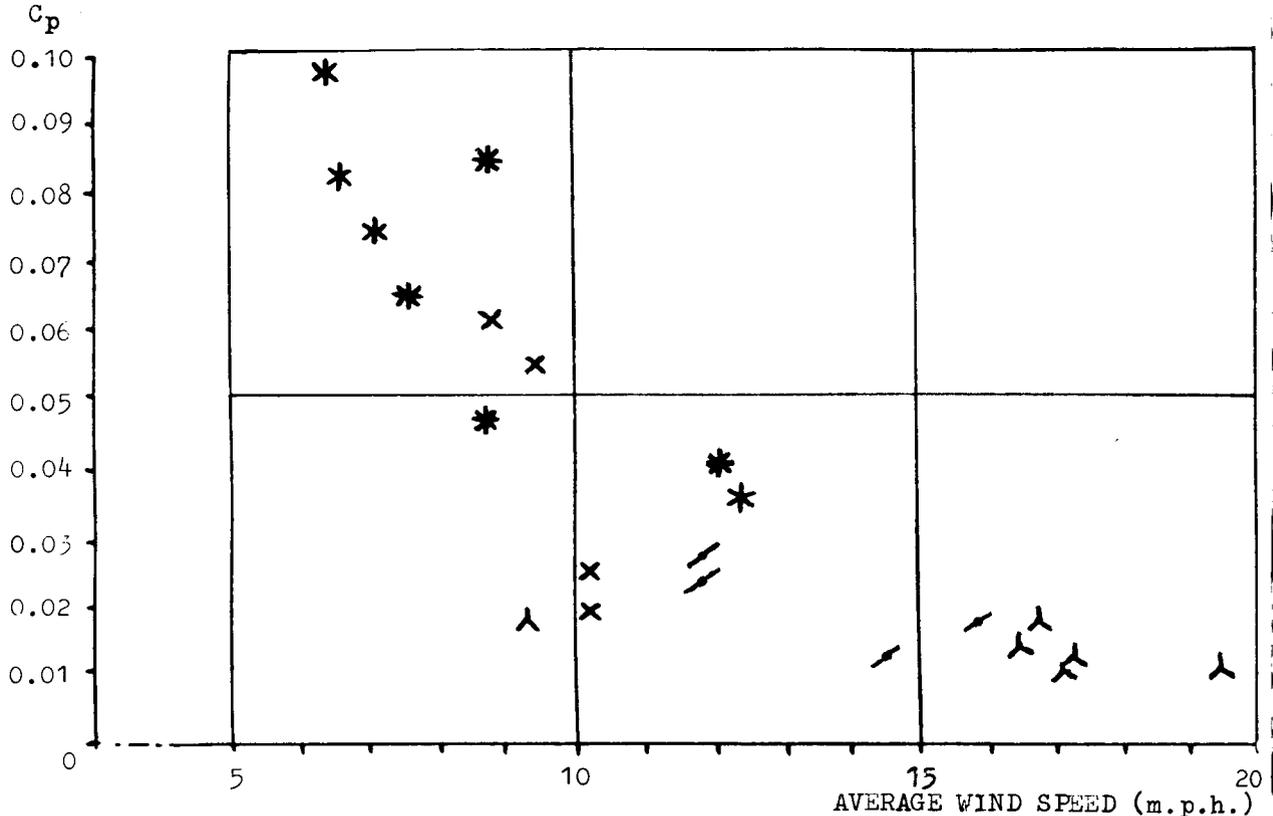
^₁₄ ^₁₄

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17

WIND SPEED
(miles/hr)

VARIATION OF THE COEFFICIENT OF PERFORMANCE FOR 14ft WIND-MILL

Each star on the graph gives a measure of the overall system efficiency at a given average wind speed. The number of points on a star indicates the number of sails fitted for the test.



This graph suggests that the C_p (coefficient of performance) is influenced more by the wind speed than by the number of sails fitted - provided sufficient sails are fitted to give reliable operation.

The indications from this are that the following numbers of sails are appropriate with this size of wind-wheel (14ft):-

<u>no. of sails</u>	<u>wind range</u>
6 or 8	6 - 12 m.p.h.
4	8 - 16 m.p.h.
3	12 - 20 m.p.h.
2	16 - 30 m.p.h.

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