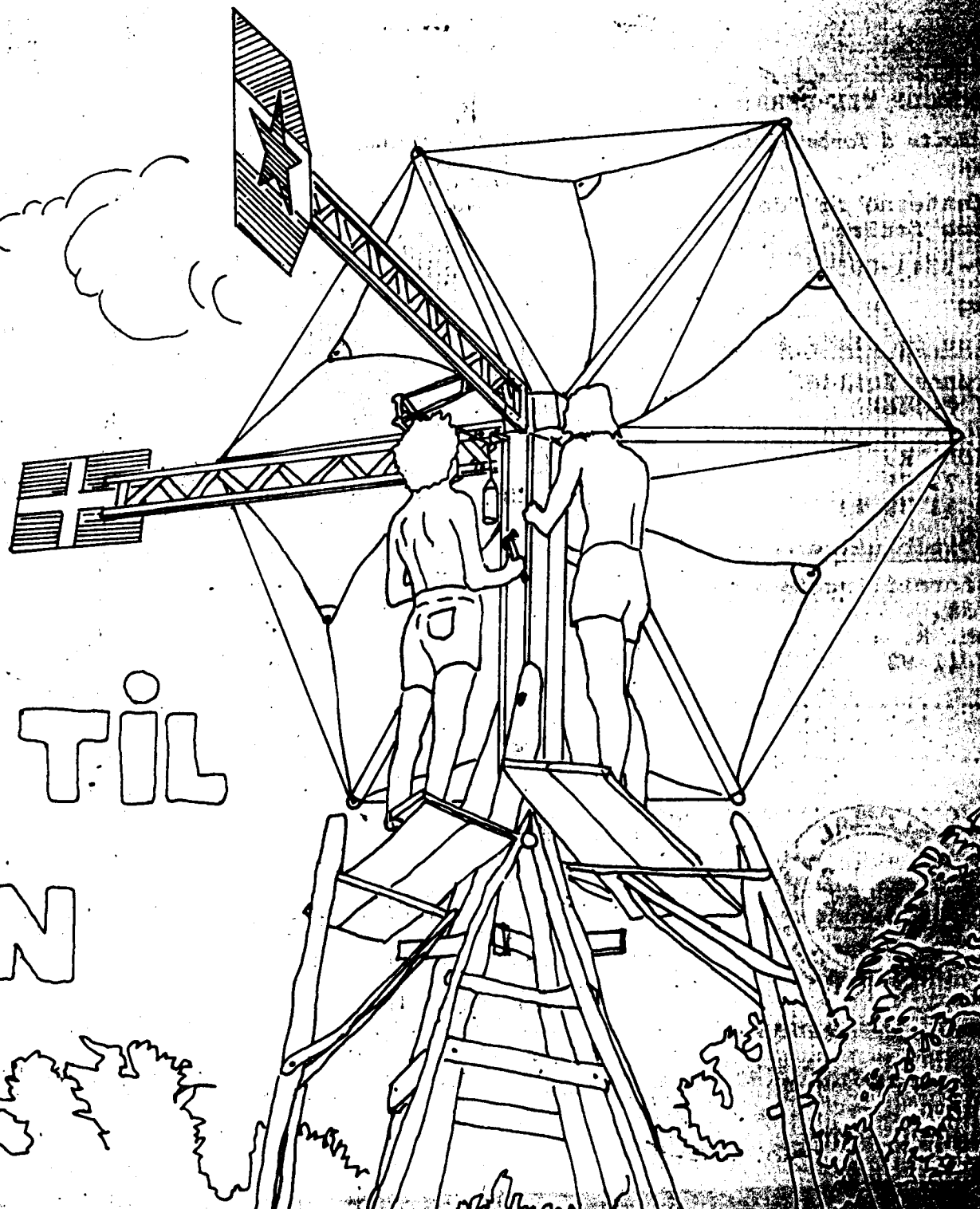
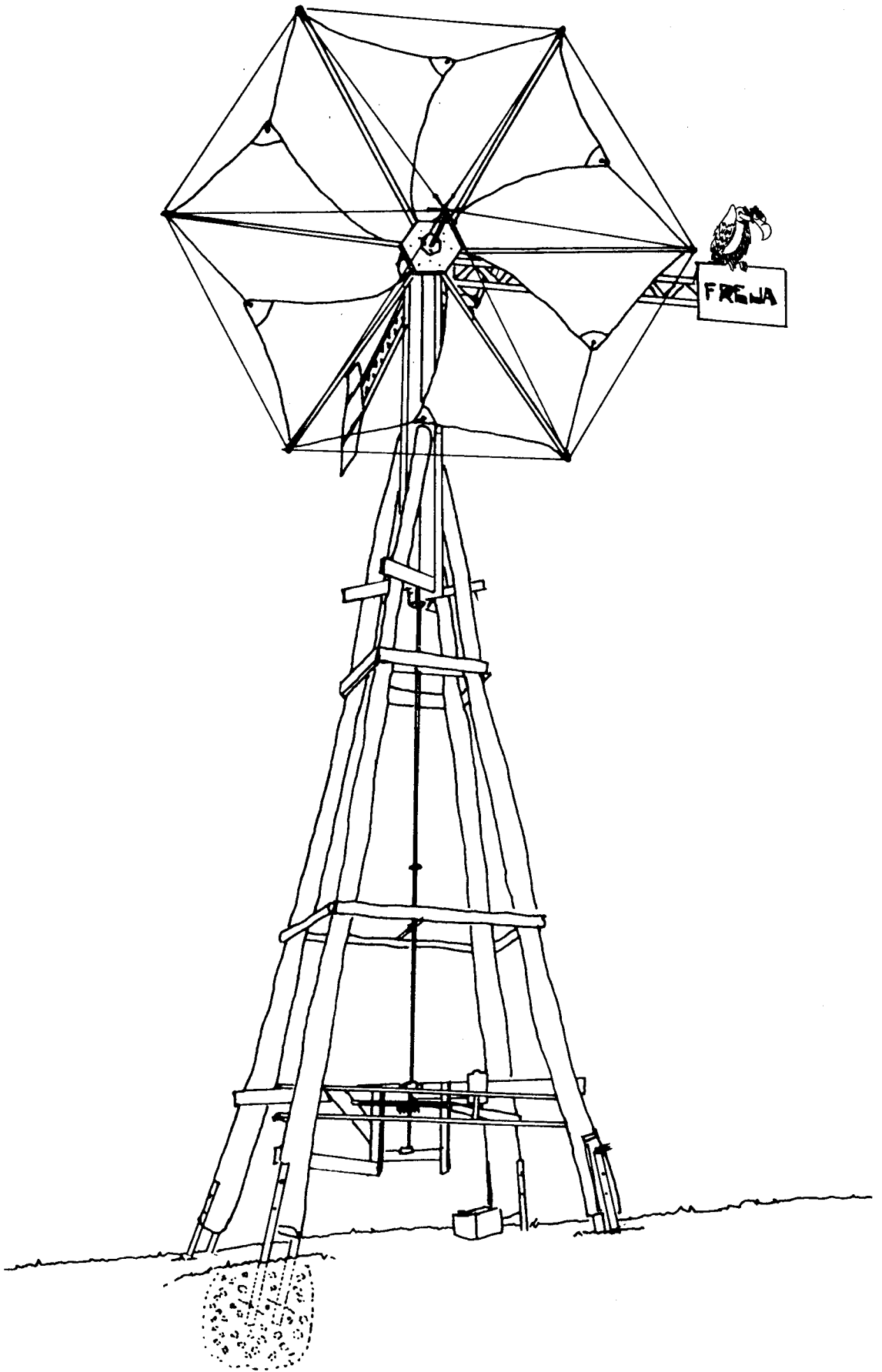


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Sail Windmill Project

In February 1978 - a group of students from Institute 3A - The School of Architecture - in Copenhagen Denmark were invited to visit the native village of one of their fellow students - Milorad Karadiz from Serbia in Yugoslavia.

The students designed and built a sail windmill to bring with them as a gift and as a demonstration project for the village inhabitants and as a contribution towards the introduction of Renewable Energy technology.

The village of Novi Durevac has no access to electricity and the nearest grid connection is 8 kms away in the larger village of Zitni Potok.

For lighting - the Karadiz family have installed 6 units of 12 volt fluorescent lights in their house and barn. Power is supplied from old car batteries - transported every 14 days by ox-cart to Zitni Potok for re-charging.

The windmill would be erected on a small mound in the garden for charging the lighting system's discharged or flat batteries. A direct electrical connection to the house would result in too high a power loss.

The windmill should be based on recycled materials and have a technological level equivalent to what local village inhabitants and the local blacksmith could be expected to reproduce.

It was the intention to demonstrate to the other villagers how one could produce electricity from the wind, as an intelligent alternative to centralized electrical power stations that are not only resource-intensive but also discriminate against distant rural areas resulting in emigration from the countryside to the towns.

The windmill should also be able to charge batteries belonging to neighbours - in addition to providing mechanical power for water pumping, sawing wood, etc.

Our first step was to ask Claus Nybroe to assist us in getting started. He acted as our source of inspiration and technical consultant and together we were able to choose the blade-design and to estimate the expected production.

The most important detail - information on the available wind was sparse, inaccurate and disappointing. Wind data from two larger towns - about 150 kms distant from Novi Durevac showed an average wind speed of about 1½ - 2 meters pr. second.

However mountains and hills are different from larger towns and Milorad informed us that the wind was stronger in the mountains with often strong gusts. However as the average yearly wind-speeds are rather low, - we had to consider

some form of multi-blade farm-type windmill that could utilize the available low wind speeds.

The actual construction was done in the School of Architecture's workshop - where we received assistance with welding and machining etc. During the final construction period we were visited by Jacob Bugge from the Danish Technical University who pointed out some errors, - assisted us with different calculations and suggested practical alternative solutions for such things as "turning out of wind". He informed us- that he thought that the windmill looked "good-enough"- but that we would first know whether theory also agreed with praxis after the windmill had been in operation for a while - this last information was later shown to be very true.

Progress in the workshop was very slow - we were only 2 - 3 persons and our task was a mix of both design and construction.- we were finally able to finish the task with a great effort and with the assistance of friends - only 14 days before the windmill was due to be transported to Yugoslavia.

The slow rotational speed of this blade design requires a high gearing to produce sufficiently high dynamo rotational speeds. We also had to consider the possibilities of the powerful gusts of wind and provide the windmill with a tail-construction to turn the windmill out of the wind so as not to overload either the blades or the dynamo.

The requirement for the use of re-cycled materials - gave us many deliberations as to just what we could expect to find in a Serbian junk-yard - Milorad thought that used car parts were more abundant than used bicycles. These deliberations had to be combined with what we in the concrete situation could find back home in Denmark. This resulted in many unusual choices. [Outside observers often pointed-out easier and more efficient solutions which did not however take fully into account our absolute requirements of low-technology and re-cycling of resources].

This was a very important parameter for us - as the windmill should fit into the already existing technological level and at the same time fall inside the framework of the local practical-technological capability - which can be of course limited by the resource base of existing on-site tools and machines.

During the final 14 days we built and erected a tower and carried-out a preliminary trial-run, where we did not have time to try-out the gear and electrical equipment. This was an unfortunate omission as these particular components gave us several problems later.

However we were all in good spirits when Milorad drove off for home in his 4-wheel drive Unimog with the loaded - disassembled windmill.

Blades

The blade type that we used are similar to those used for centuries by the Greeks in Crete. Six wooden poles - covered with canvas - radiating out from a wooden hub and all joined and connected together with steel wire to stiffen the construction.

To keep the rotor away from the tower - the poles, spars or masts are set at an angle of 7° - [**7 degrees**] - away from the vertical position by wooden wedges placed in the hub and by the use of steel wires running from each mast-tip or cap to an extended axle or bowsprit.

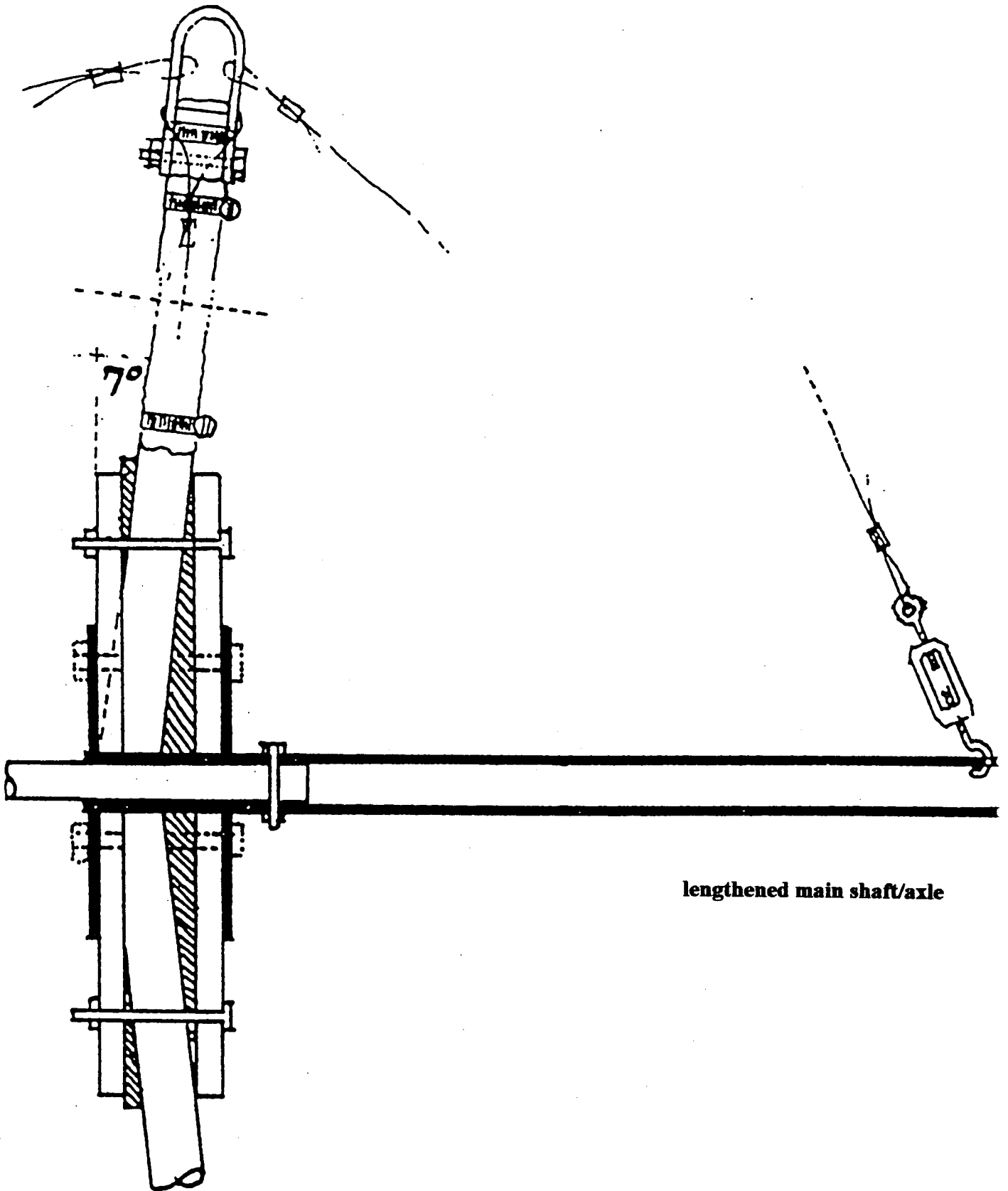
The hub is made of 2 pieces of waterproof plywood. - wooden spacers are placed between the poles to maintain the correct distance between the two sides. The completed unit is bolted onto an iron pipe with a welded flange and a loose plate.

The canvas sails are sewn with extra reinforcement pieces at attachment points and the sails are treated with sheep's-tallow [fat] to prevent soaking.

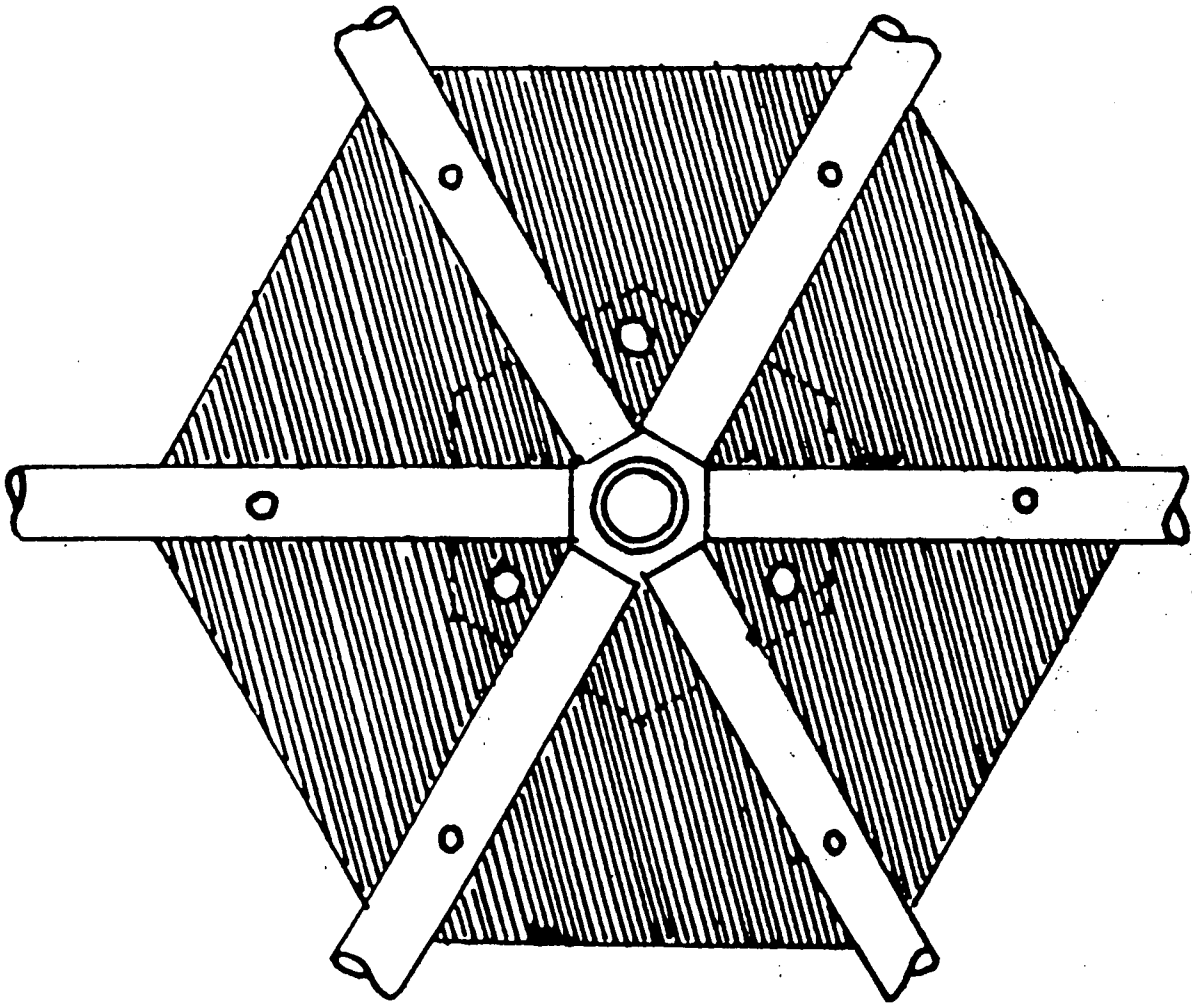
During periods of high wind speeds the sails will stall - and will therefore not increase their rotational speed above a certain level. As an additional safety factor - the rope that holds the sail in position will rupture - if the force of the wind threatens to tear the sails or break the spars.

The rotor diameter is **3.20 m.** and the swept area is **app. 3.5 m².**

sail masthead cap with wire stay rigging



lengthened main shaft/axle



hub with front plate removed

Nacelle and Turntable.

The rotor requires a high gearing and as we did not wish to use a gearbox - this could be difficult or expensive to find in Serbia - the power was transmitted down through a vertical shaft.

The gearing system using several wheels and a V-belt pulley-drive took up so much space that there was not sufficient room on the nacelle upper bed plate.

A bearing construction is placed on a 5 mm iron bed plate. A bevel drive gear or crown-wheel on the horizontal steel axle inter-meshes with a shaft drive pinion fastened to the upper end of the vertical shaft.

To enable the windmill to turn into the wind - the upper section is mounted on top of another iron plate. A thick layer of grease prevents friction between the two plates.

4 iron strips or “flaps” are fastened to a pipe welded to the bottom plate. These strips are to bolt the whole construction to the upper vertical wooden tower section.

The rear tail boom assembly is bolted to the rear end of the upper rotating section - positioned on top of the bottom fixed plate. The wooden vane is fastened to the tail assembly with a piece of angle-iron. The side-mounted tail boom in a similar fashion - is bolted to the front end of the upper rotating bearing section.

Due to the flimsy construction the nacelle had several weak points. The force from the blades bent the 5 mm. thick iron bed plate. This resulted in unsatisfactory inter-meshing of the bevel gear teeth due to displacement of the bearing case.

We were unable to construct a satisfactory cover for the nacelle at the workshop in Copenhagen. This was a task for Zitni Potok's skilled and effective tin-smith who supplied the local surroundings with buckets and containers. Inside an hour - he bent, hammered and riveted a suitable “hat-cover”. We had made a small drawing, but he had no use for that. He just took a large cardboard-box - cut it with a pair of scissors and then asked us - “Does it look like this?”.

The shaft drive pinion gear wheel's mounting on the transmission shaft with a keyway or slot and a locking ring was a further weak point. The locking ring slipped off when the machined mounting track on the shaft became worn. We had neglected to have the transmission shaft hardened.

furling/shut-down system

90° - Overspeed side windvane

turning arm

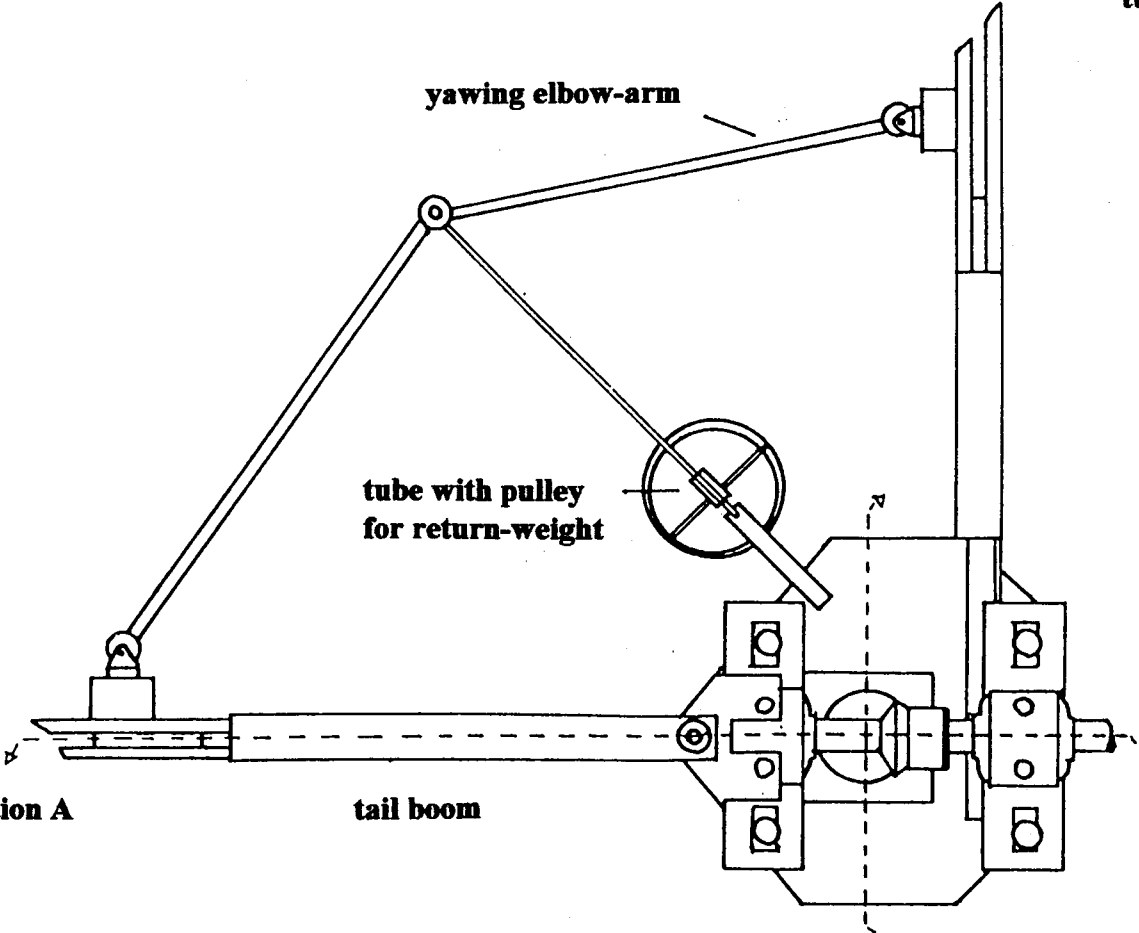
yawing elbow-arm

**tube with pulley
for return-weight**

nacelle - section A

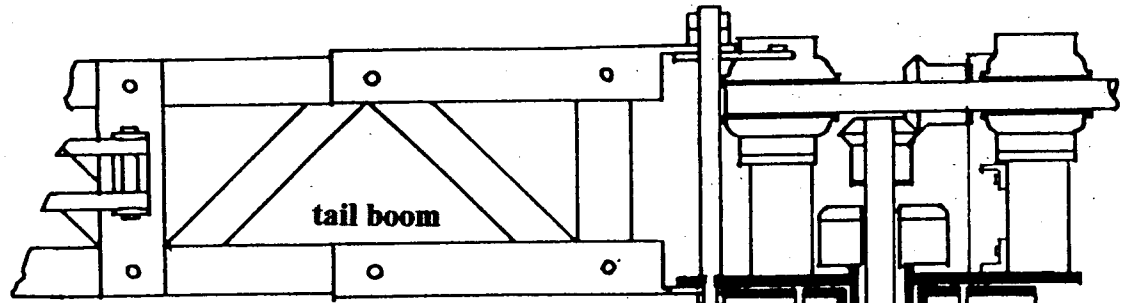
tail boom

nacelle - section B



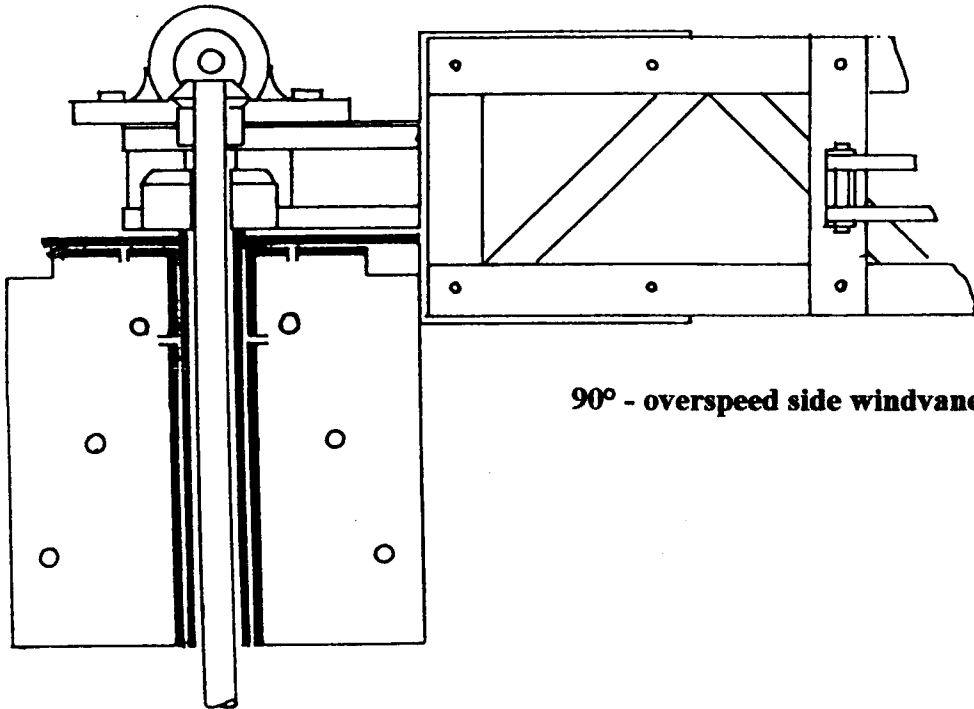
tail wind vane boom

nacelle - section A



tail boom

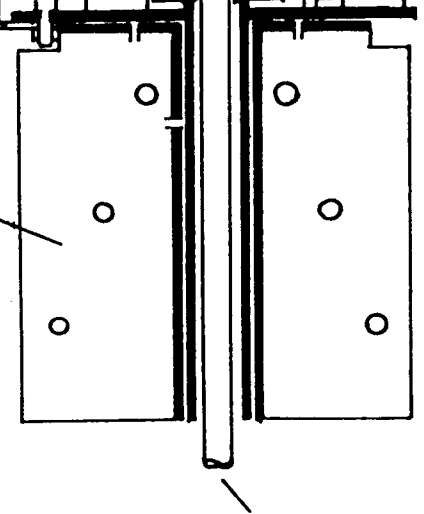
nacelle - section B



90° - overspeed side windvane

vertical shaft

**lower bed-plate
attachment fittings**



vertical transmission shaft



tinsmith making the nacelle cover

Gearing

We had difficulty in calculating the gear ratio as we could find no exact formula concerning the blade-tip speed and the effect of our chosen blade type. With the assistance of Claus Nybroe - we approximately estimated - a maximum dynamo effect at **2400 rpm.** - the gearing should therefore be **app. 1 : 28** - as the rotational speed of the blades was estimated to be about **87 rpm.**

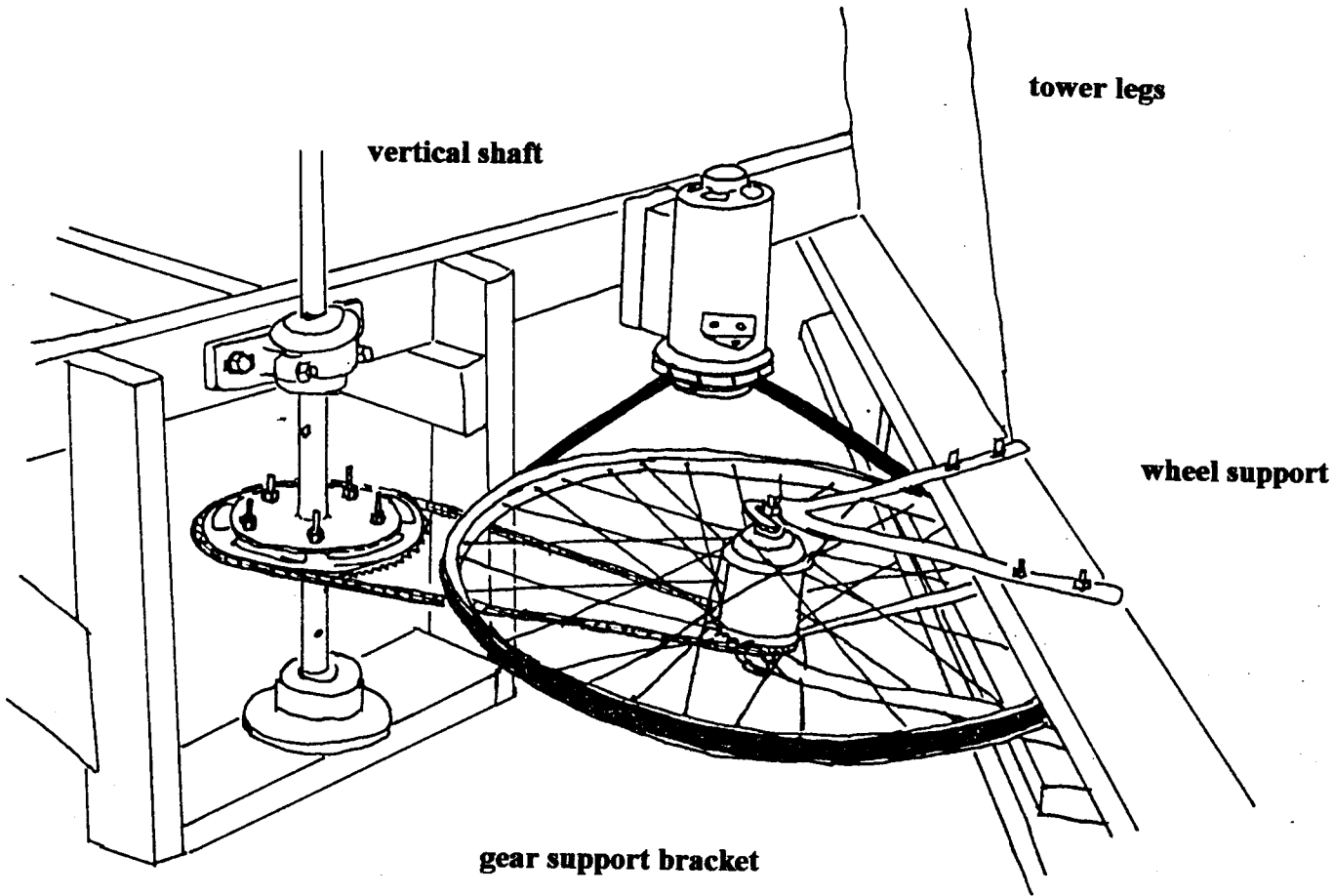
The main gear is placed at the foot of the long **5.5 m.** vertical transmission shaft. This shaft is supported by **3** wooden oak block bearings. These bearings are each made from two blocks of oak boiled in linseed oil. The bearings are then fixed around the shaft as seen in the drawing -and will absorb the radial thrust and prevent unwanted sideways movement and vibration in the shaft.

The shaft is made of three lengths with welded flanges to enable coupling [thick rubber washers should perhaps be placed between the flanges - note by JF.]. The power take-off - a **52-teeth** bicycle crank-wheel - is positioned between the fixed ball bearing and the lower bearing support.

A bicycle chain goes from here over to a **22" [22 inch]** bicycle rear-wheel equipped with a **14-teeth** gear wheel. A V-belt goes from the inside rim over to the dynamo's V-pulley wheel.

This construction gives the required **1 : 28** gearing. There is also the possibility of a gear-shift to a lower gearing as the wheel hub is equipped with a 3 speed - Sturmey Archer hub gear. This allows the possibility of compensating for possible calculation errors concerning the windmill gear ratio.

The wheel, dynamo and bearings are supported by brackets and fittings on the tower-leg horizontal cross pieces. These cross pieces are subject to strong vibrations during periods of strong wind - resulting in a risk of the V-belt falling-off. A much stronger reinforcement of the cross pieces is necessary.



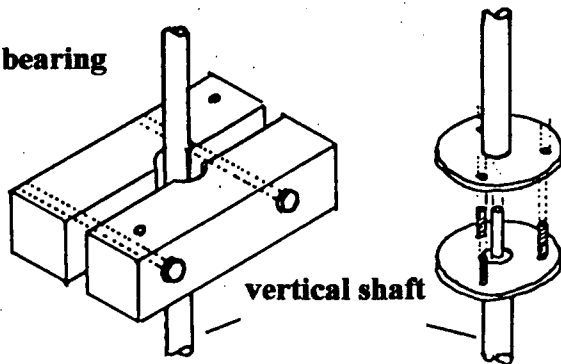
vertical shaft

tower legs

wheel support

gear support bracket

oil-soaked oak wood bearing



vertical shaft

vertical shaft coupling

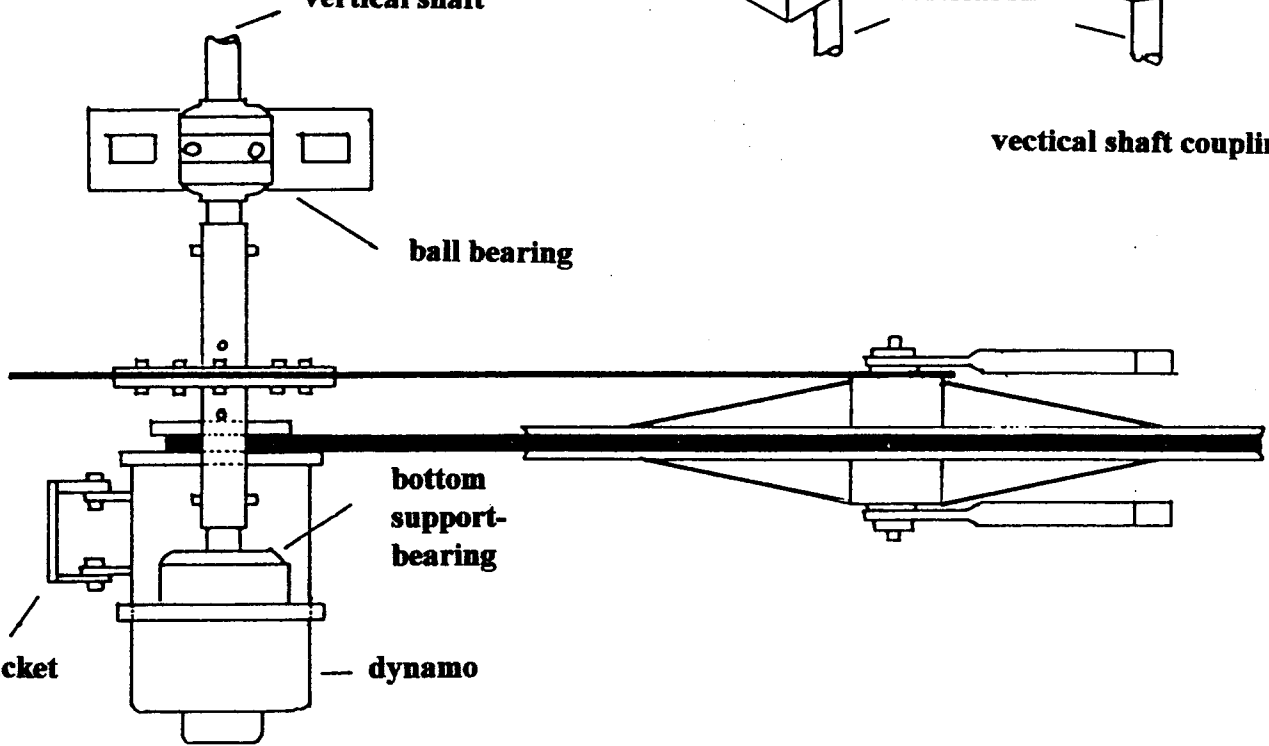
vertical shaft

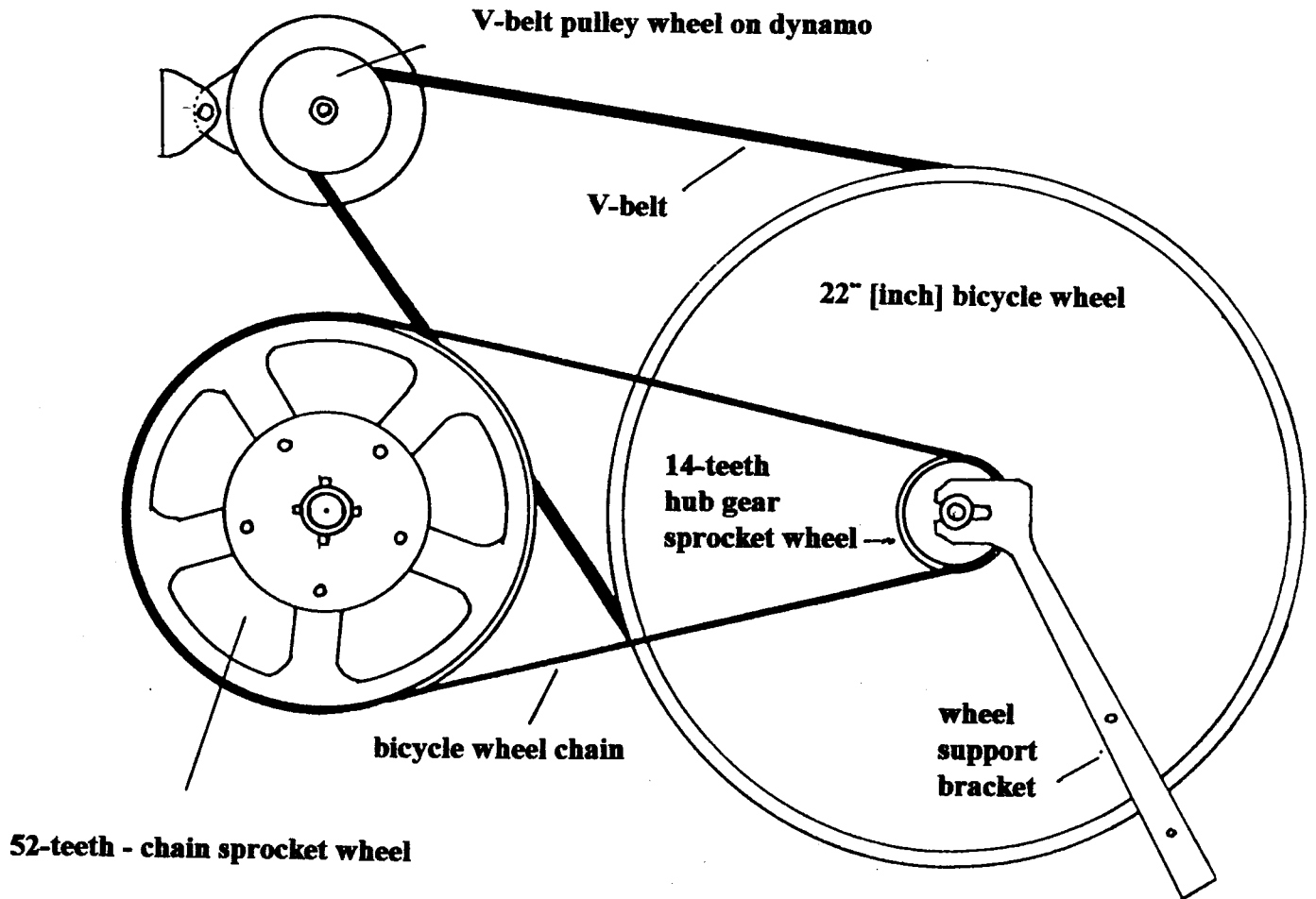
ball bearing

**bottom
support-
bearing**

dynamo

bracket

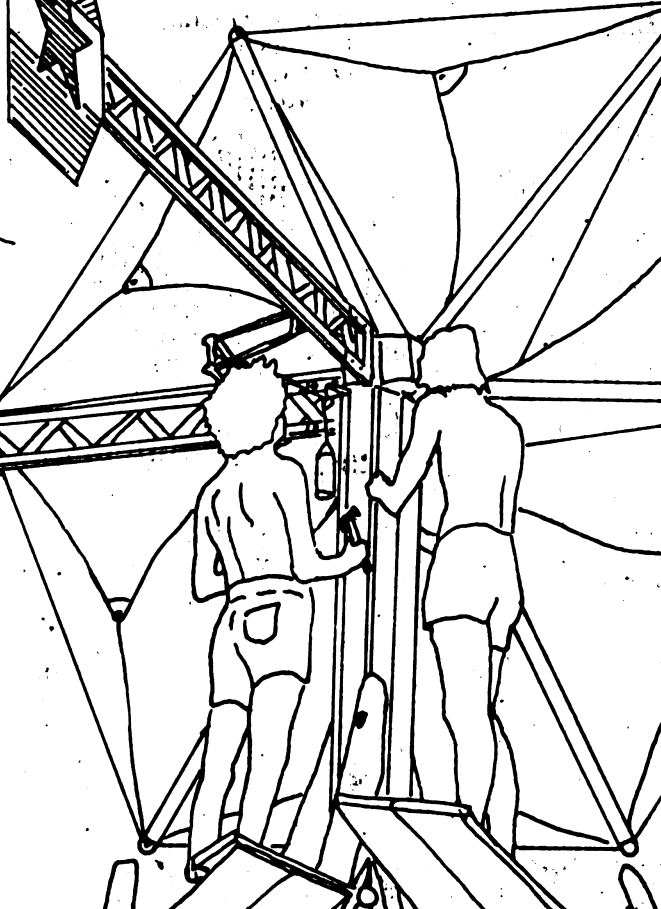




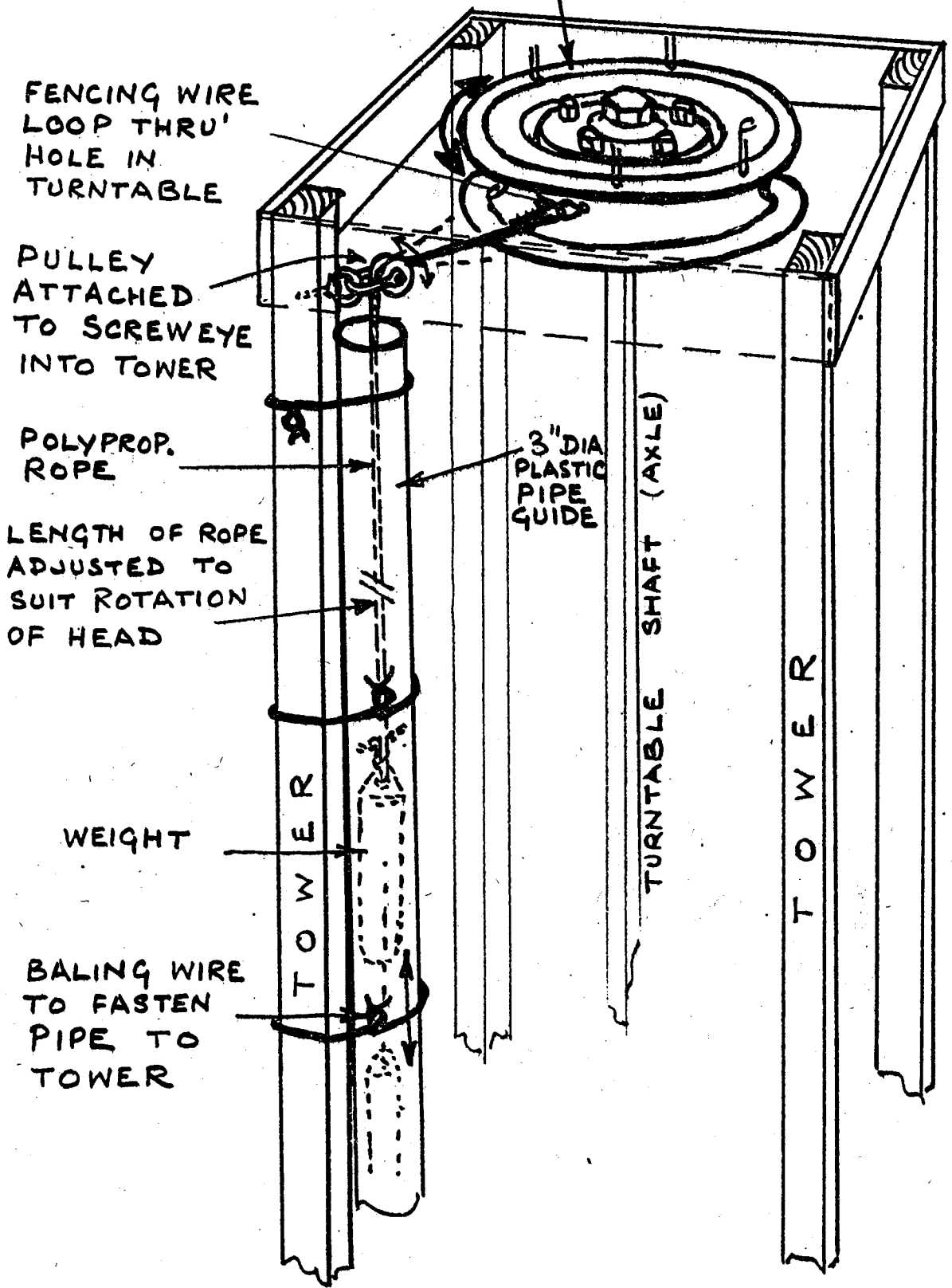
Tail and Side Wind-Vane

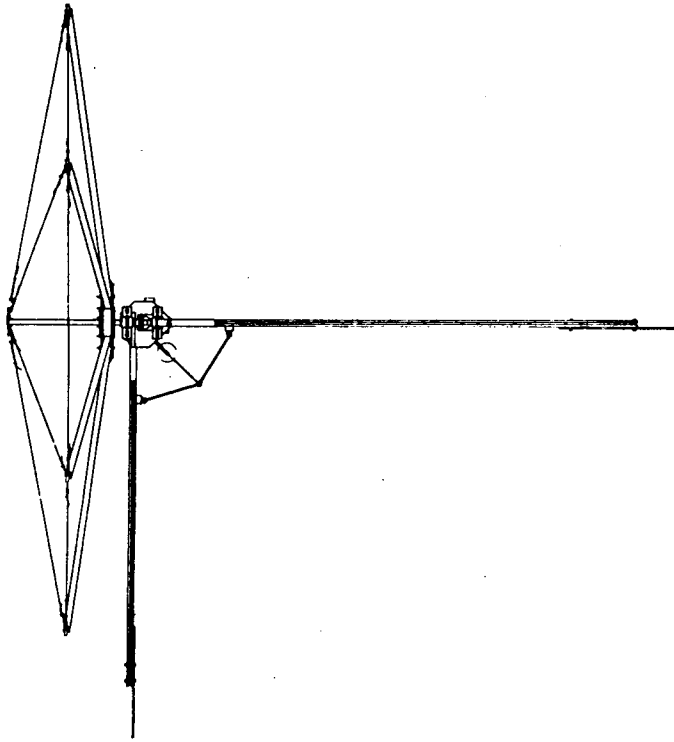
The very strong girder construction of the tail and side wind-vanes was made of **1.5 cm.** thick - wooden laths - to reduce the weight.

A spring mechanism was first used to return the side vane and the rotor back to an operative position. This was later abandoned in favour of a “Falling-weight” - [this principle is clearly shown in a following diagram taken from another project]. When the windmill turns out and away from the wind - the falling-weight is pulled up. The weight’s “return-force” is therefore able to return the windmill to the start position as soon as the force from the excess wind speed has lowered.

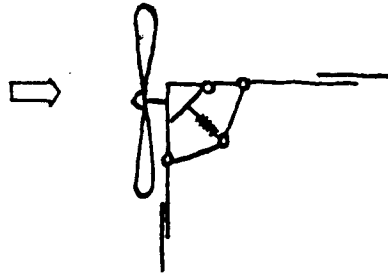


(ROAD WHEEL) TURNTABLE CARRYING CRADLE

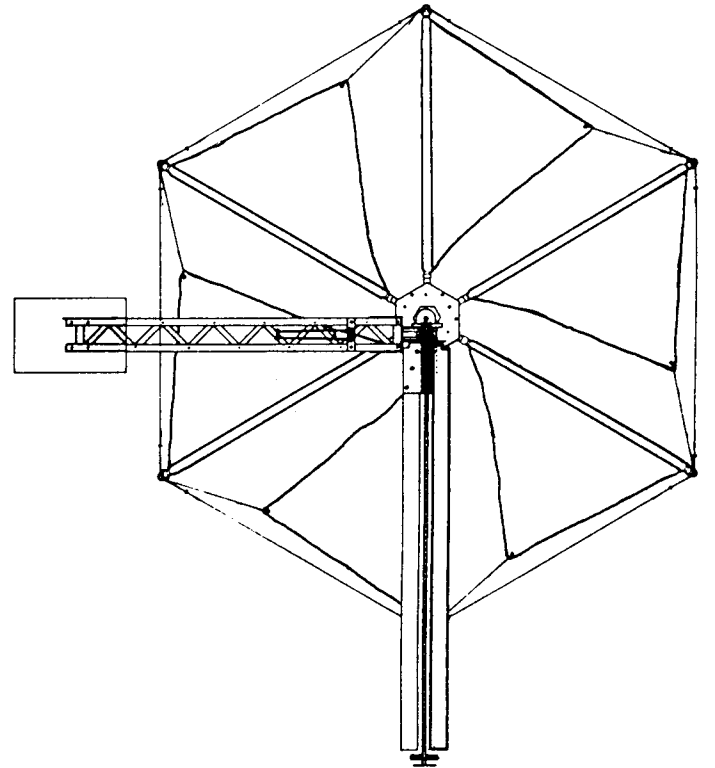




turning/yawing arm



yawing system



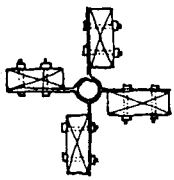
Tower

The experimental tower - built in Denmark - was too big to be transported to Serbia, - and a new one was constructed on site.

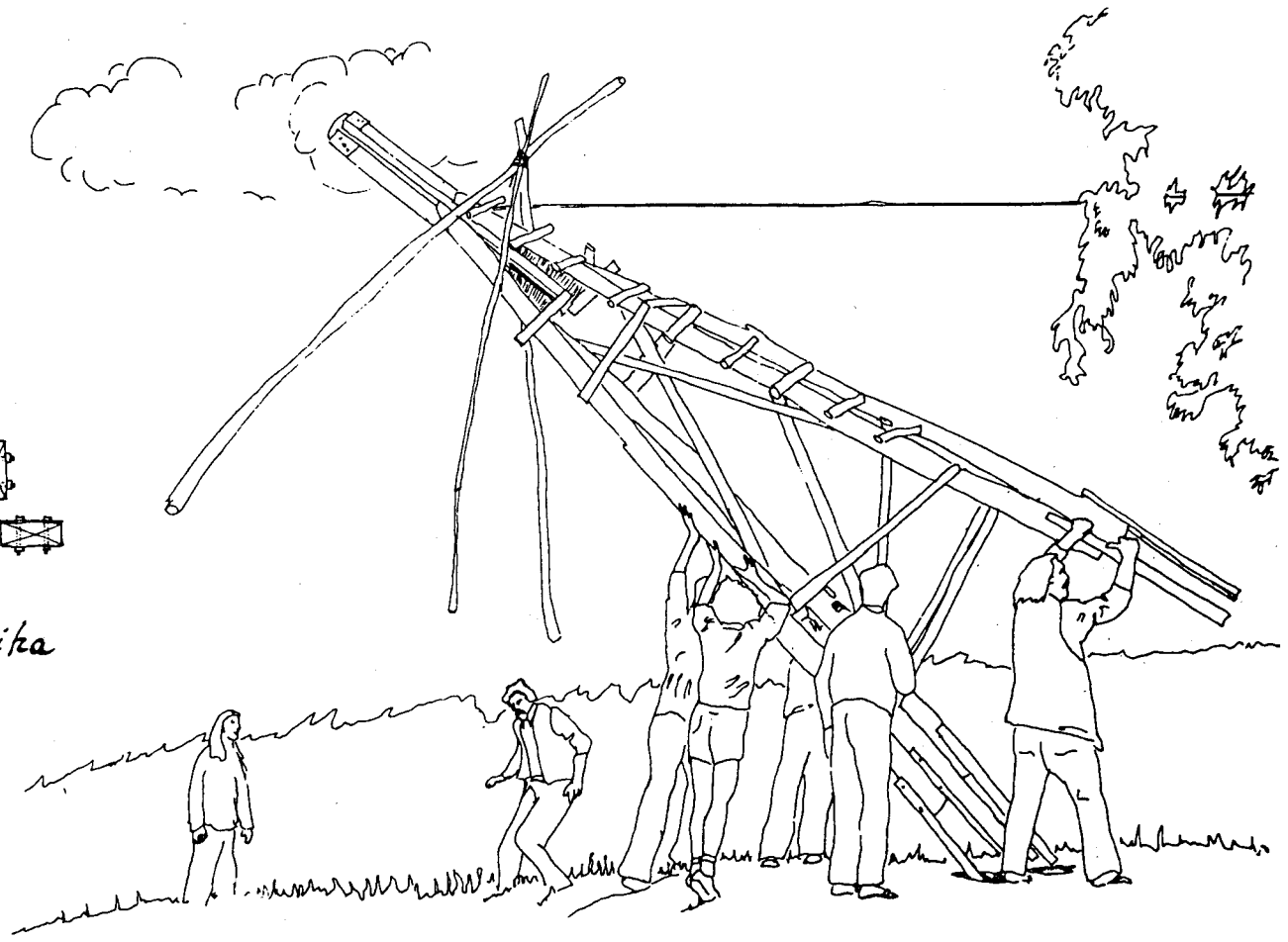
The upper **2 m.** vertical wooden tower section - was assembled in the form of a svastika - bolted onto the lower nacelle bottom plate “flaps”. This section was then bolted onto the angled tower legs. Wooden cross pieces were then fixed to provide additional constructional stiffness.

The rough and uneven tower oak poles gave many problems. This was erected with the assistance of the 4-wheel drive Unimog truck. Four foundation holes were excavated **70 cms.** down into the solid rock. Each leg was fitted with two bolted-on lengths of angle iron - to provide a good join with the concrete poured into the foundation holes and to raise the wooden legs app. - **15 cms.** above ground level.

Following the tower erection - a home-made scaffolding was built to enable the nacelle, top covering and the rotor to be mounted in place.



Svastika



The Electrical System

Dynamo

Most newer cars use an effective AC-generator called an alternator. Alternators however require a starting current from a battery to energise the system [magnetise the stator]. This means that during periods of no-wind - this requirement could discharge the battery.

A dynamo will start to charge at about 1000 rpm - it will have a maximum effect at about 2400 rpm and highest rotational speed at about 7000 rpm.

NB: - If the dynamo has been unused for a long time - or if it has been run in reverse. There is a possibility that the remanence or residual magnetism has been lost. [that is - the iron core has lost it's magnetism and must therefore be re-magnetized].

The dynamo is connected to a battery [both a 6 V or a 12 V - battery can be used] - and run as a motor for an instant. The dynamo is re-magnetized and is therefore now able to produce electricity and charge batteries. This method is also a good test of of a dynamo - if these are purchased second-hand. If a dynamo cannot run as a motor - it is fairly certain that it is defect.

Relay

The function of the relay is to regulate the current and voltage produced by the dynamo. A relay is an iron core wrapped with a copper wire winding [a spool]. When current is sent through the spool - the iron core is magnetized - and is able to attract an loose iron plate [the relay armature]. The relay armature is connected to one or more electrical contacts - which are then opened or closed.

There are several different manufacturers and many different types of relay's available on the market - differing in numbers of spools and armatures. It is important when purchasing a relay to ensure that the dynamo and relay can function satisfactorily together. And to ensure that the they both have **plus** [+] or **minus** [-] to earth [ground].

Electrical Wiring

Current-loss in a low-voltage system is quite considerable. This means that one must place the windmill in the near vicinity of the power consumption if one does not wish to use arm-thick power cables. We chose to place the batteries at the foot of the tower, enabling us to use normal household electrical wiring. Every week or so - the discharged battery from the house must be exchanged with the now fully charged battery from the windmill. If we had chosen to lead the current 20 meters - directly into the house - we would have required a cable with a thickness of **10 mm cross-section** - as can be seen in the nomogram.

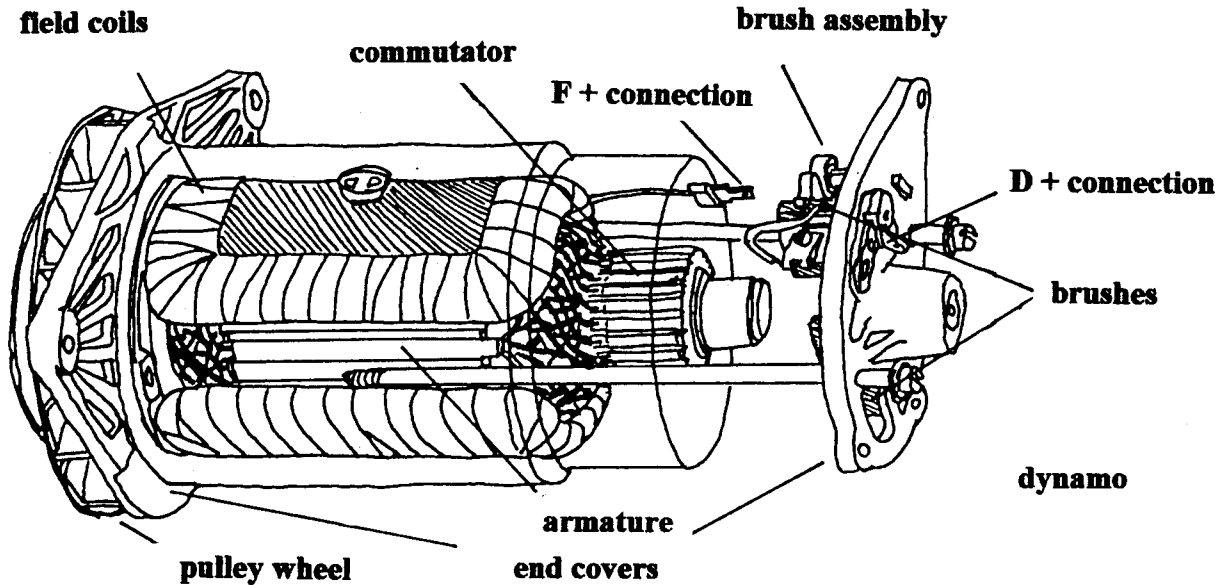
Battery

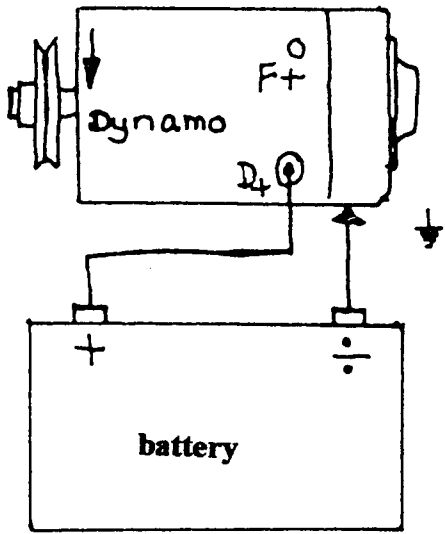
A car battery is not the most efficient for windmill use - as it is constructed for many small charges and discharges - and is not very suitable for deep discharging. We were fortunate in obtaining a battery from a fork-lift truck - nearly an ideal type - built for hard daily use with a night-time re-charge.

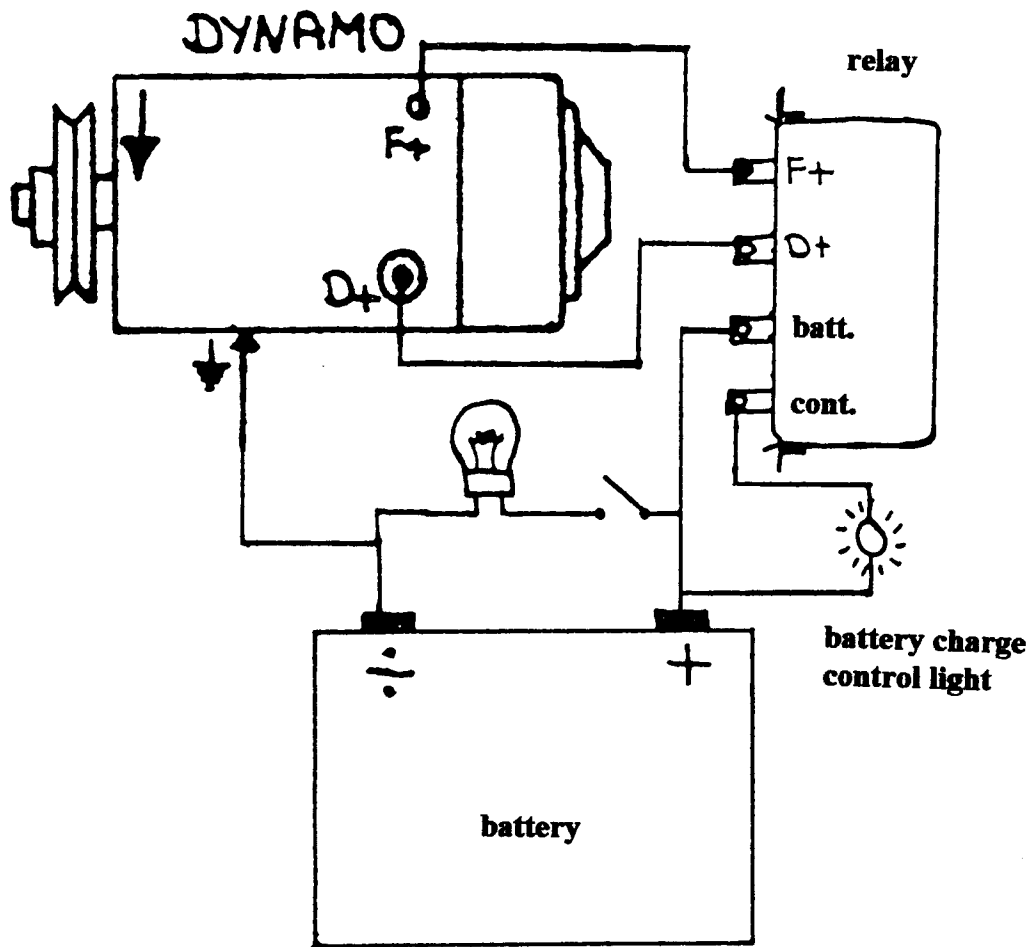
The battery size must also roughly correspond with the dynamo's electrical production capacity or effect - as can be seen from the following table.

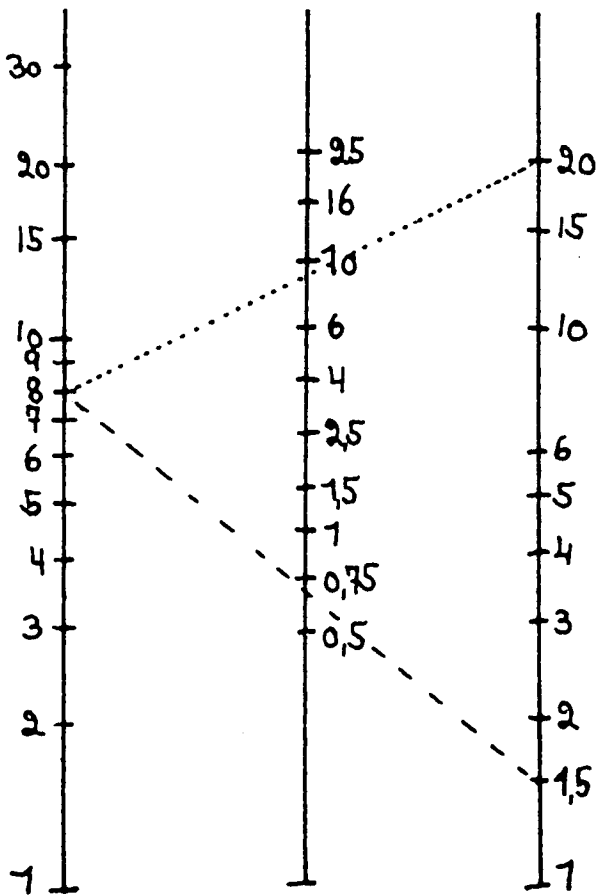
Batt. - Amp/hours	105	150	300
Dynamo	130	200	500

Batteries that are not often used - will suffer a chemical discharge and over a longer period of time the cells are destroyed. If a battery is left unused for a longer period - it must therefore be charged from time to time and distilled water must be added to the cells. [self-discharge is roughly about **0.7%** of the battery capacity pr.day]









**current
strength
in Amps**

**mimimun
cross-section
area in sq. mm.**

**wire length
in meters**

Total Costs

If one has time to look through junk-yards and if material is bought through scrap-merchants etc. - a windmill can be made at very low-cost.

Our cost list from 1978 - does not include the the expense of the tower.

Bearings including housing	-----	App \$ 35.00 USD
Top bevel gears	-----	5.00
Spars - etc.	-----	26.00
Iron sheet/plate	-----	17.00
Angle-iron	-----	3.00
Wood and plywood sheets	-----	23.00
Various bicycle components	-----	35.00
Dynamo with V-belt and relay	-----	27.00
Nuts - Bolts, screws etc	-----	131.00
Battery	-----	43.00
Extras	-----	10.00

Total app: \$ 355.00 USD.

EN VINDMØLLE TIL SERBIEN

af Kim Høite & Torben Eriksen
FREJA

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