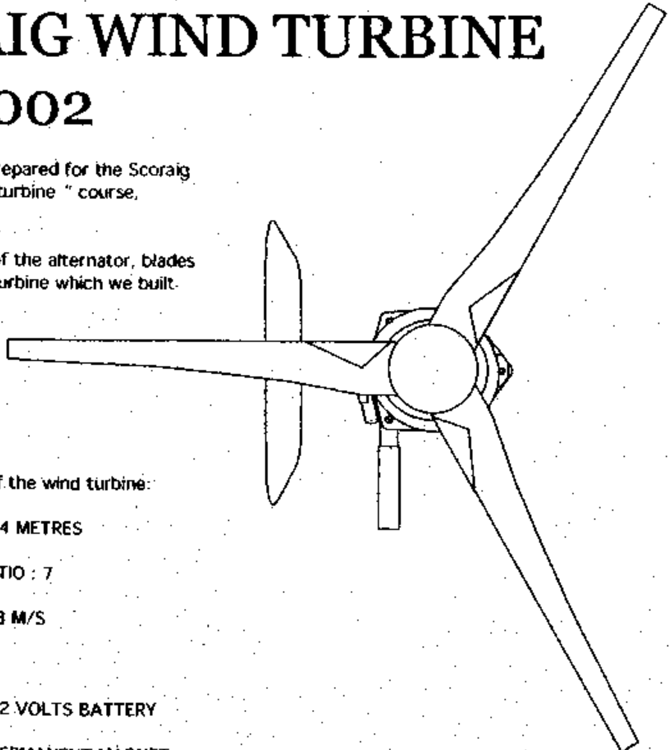
SCORAIG WIND TURBINE
MAY 2002

This document was prepared for the Scoraig "How to build a wind turbine " course, 11-18 May 2002.

It contains drawings of the alternator, blades and frame of a wind turbine which we built during the course.



The basic statistics of the wind turbine:

ROTOR DIAMETER : 2.4 METRES

DESIGN TIP SPEED RATIO : 7

CUT-IN WINDSPEED : 3 M/S

CUT-IN RPM : 170

SYSTEM VOLTAGE : 12 VOLTS BATTERY

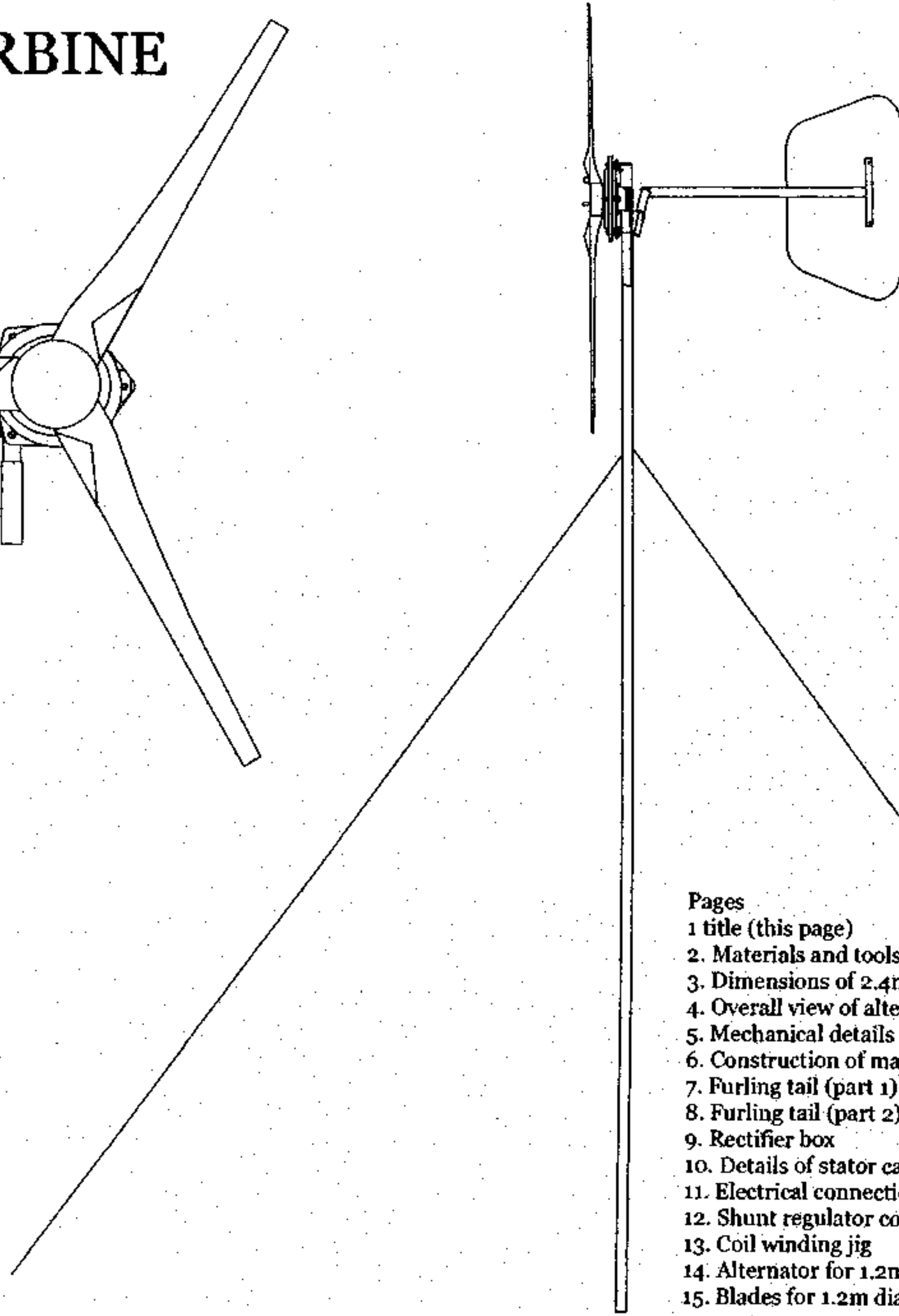
ALTERNATOR TYPE: PERMANENT MAGNET

MAGNETS : 12 POLE PER ROTOR
NEODYMIUM IRON BORON N40 GRADE

COILS : 10 COILS SET IN RESIN DISK TO GIVE 5-PHASE OUTPUT EASILY CONVERTED TO DC

PREDICTED OUTPUT: 12 VOLTS AT 170 RPM
14 VOLTS, 36 AMPS (500W) AT 350 RPM
AT 10 M/S, TIP SPEED RATIO 4

OVERSPEED PROTECTION BY FURLING TAIL



Pages

Materials for wind turbine per unit	qty	size	Total wt. g	Source address		NOTES ON SUPPLIERS PHONE AND ASK THEM FOR CATALOGUES
FIBREGLASS SUPPLIES				Glasplies	Tiranti	Glasplies have very useful information packs
Polyester resin (premixed with accelerator)		approx	2500g	2, Crowland St.	70 High St.	
Catalyst (peroxide)			50g	Southport	Theale	
Talcum filler powder			1200g	Lancasire	Reading	
Fibreglass mat (1oz/sqfoot)		1 sq metre	300g	PR9 7RL	Berks	
				(01704) 540 626	(01734)302775	
MAGNETS				CERMAG Ltd	Magna Co. Ltd	Magna supply the blocks with Ni coating
					Tokyo,	
				94 Holywell Rd.	<sales@magna-	
				Sheffield, SA4 8AS	tokyo.com>, +81	
NDFEeB GRADE 40 (optional Ni coating)	24 blocks	46X30X10	2500g	(0114) 244 6136	3 33763864	Uncoated magnets will corrode in air.
ELECTRICAL				EC WIRE LTD	Percy Hawkins	EC wire supply high temperature enamelled wire
Enamelled winding wire		16AWG or 1.4mm	3000g	(01924) 266 377	(01536) 523 229	Hawkins and electronics catalogues wire is solderable
flexible wire (1.5mm heat resisting)	10m	1.5mm2		FARNELL	JPR Electronics Ltd	Farnell and Maplin good but expensive
solder and sleeving for connections				WWW.FARNELL.COM	www.jprelec.co.uk	JPR and Rapid are cheaper
insulation tape				08701 200 200	01582 470000	but have minimum order requirements
Bridge rectifiers	5	35A 200V single phase		www.Maplin.co.uk	Rapid Electronics	
Heatsink for rectifiers			250g	01702 554 000	01206 751166	
STEEL				Application		
Magnet disk (or octagonal) plates	2	6mm x 300mm OD	6000g	magnet rotors		
12mm threaded rod ('studding/allthread')		600mm	450g	rotor mountings	Screwfix	Useful catalogue for tools too.
12mm nuts	24		300g		0500 414141	
12mm washers	12					
12mm threaded rod in stainless steel		300mm	225g	stator mountings		
12mm nuts in stainless steel	12		300g			
12mm washers in stainless steel	12					
5mm nuts and bolts	5	5mm x 20mm		bridge rectifiers		
6mm nuts and bolts	5	6mm x 20mm		rectifier housing/tail		
Steel angle	750mm	50 x 50 x 6mm	3000g	alternator mounts		
Steel pipe	300mm	2" / 60.3mm OD	1600g	yaw bearing		
	400mm	1.5" / 48.3mm OD	1200g	yaw bearing inner pipe		
	1350mm	1.25" / 42.2mm OD	4500g	Tail boom and hinge outer		
	200mm	1" / 33.4mm OD	500g	tail hinge inner pipe		
Flat bar		100 x 56 x 10mm	450g	tail hinge support plate		
MECHANICAL						
Bearing hub from car (Vauxhall Cavalier)	1		1250g	Scrap yard		
WOOD						
Clear timber for blades	3	160 x 35 x 1200mm	5500g			
Plywood disks for blade hub	2	13mm x 250mm OD	600g			
Wood screws to attach hub disks	54	35mm x 4mm				
Plywood for tail vane	1	10 x 900 x 600mm	3000g			
total weight of wind turbine			38675g			

Materials for moulds and jigs

Plywood or composite boards for moulds and winding jig
Silicone, Sand paper, wax polish.
(Polyurethane varnish, and PVA release agent, if available.)
Paint brushes, and thinners to clean them
Paper towels and or rags.
13mm and 16mm plywood for winding jigs and moulds

Tools

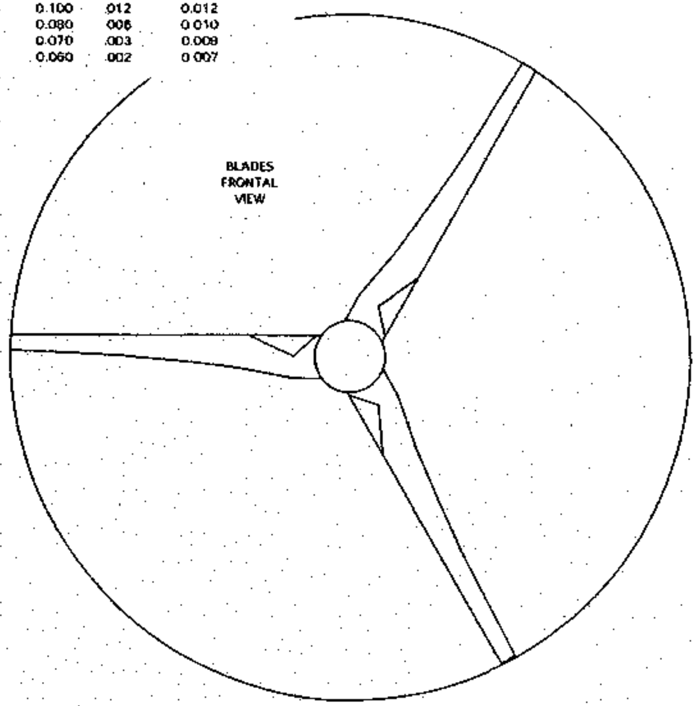
Safety goggles, ear protectors, face mask, gloves, etc. as required
Workbench with vice and G clamps
Electric arc welder, mask, chipping hammer and rods
Angle grinder with grinding and sanding disks.
Cut-off machine or bandsaw (optional)
Hacksaw, hammer, punch, chisel, files, tin-snips
Vernier callipers, steel rule, pencils, tape measure, angle/bevel gauge, chalk, compasses, spirit level.
Screwdriver, pliers, mole grips, Spanners 8, 10, 13, 17, 19mm : two of each.
Pillar Drill Press, hand drill
Drill bits 6,8,10,12mm
Holesaw 65mm
Scales to weigh resin. Dispenser for catalyst, plastic buckets, scissors.
Soldering iron, resin-cored solder, wire cutters, sharp knife.
spoons/knives for mixing (plastic/nonferrous are useful)
Scissors, felt pen, surform/rasp
Wood carving tools, draw-knife, saw, plane, spokeshave, draw-knife, oil stone.
wooden mallet, chisel
jigsaw, handsaw, circular saw

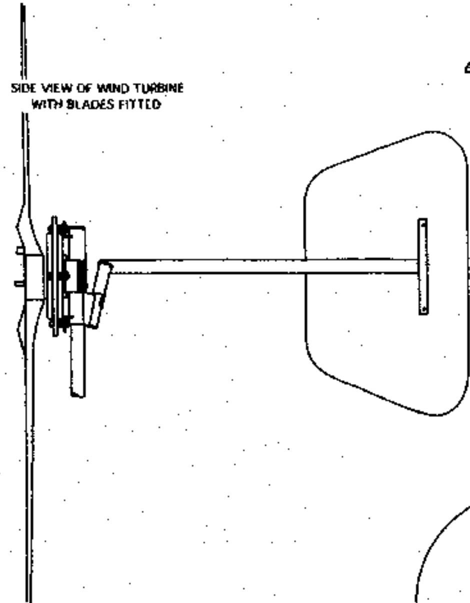
DIMENSIONS OF STATIONS
FROM ROOT OUT TO TIP
RESPECTIVELY

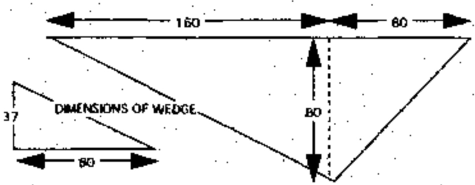
WORKPIECE

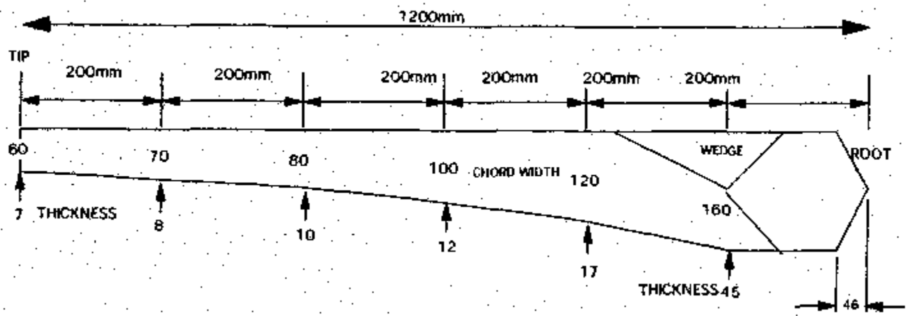
width	drop	thickness(m)
0.160	.070	0.045
0.120	.025	0.017
0.100	.012	0.012
0.080	.006	0.010
0.070	.003	0.008
0.060	.002	0.007

INCHES			
radius	width	drop	thickness
8	5 8/16	2 11/16	1 4/16
16	4 12/16	1	12/16
24	3 15/16	7/16	8/16
32	3 1/8	1/4	6/16
40	2 3/4	1/8	5/16
48	2 3/8	1/16	4/16

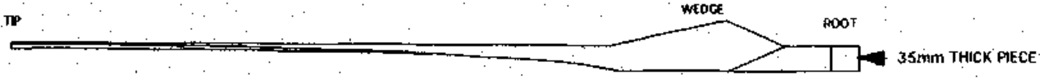




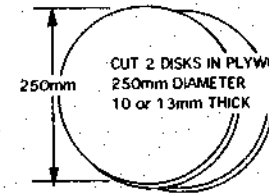


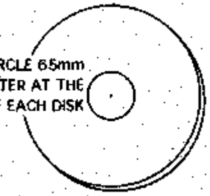


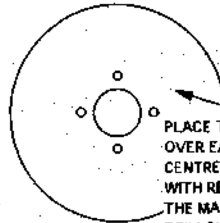
VIEW FROM THE TRAILING EDGE



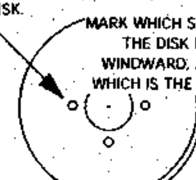
ASSEMBLING THE ROTOR HUB

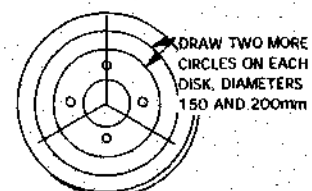


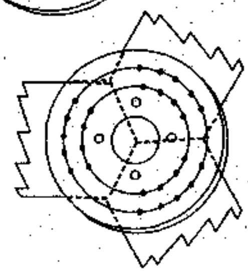




PLACE THE FRONT MAGNET ROTOR OVER EACH DISK IN TURN.
CENTRE THE CIRCLE YOU MARKED WITH REFERENCE TO THE HOLE IN THE MAGNET ROTOR.
DRILLOUT FOUR 12mm HOLES IN EACH PLYWOOD DISK.







DRILL NINE PILOT HOLES FOR SCREWS INTO EACH BLADE ROOT

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SCORAIG 'NEO2.4' WIND TURBINE
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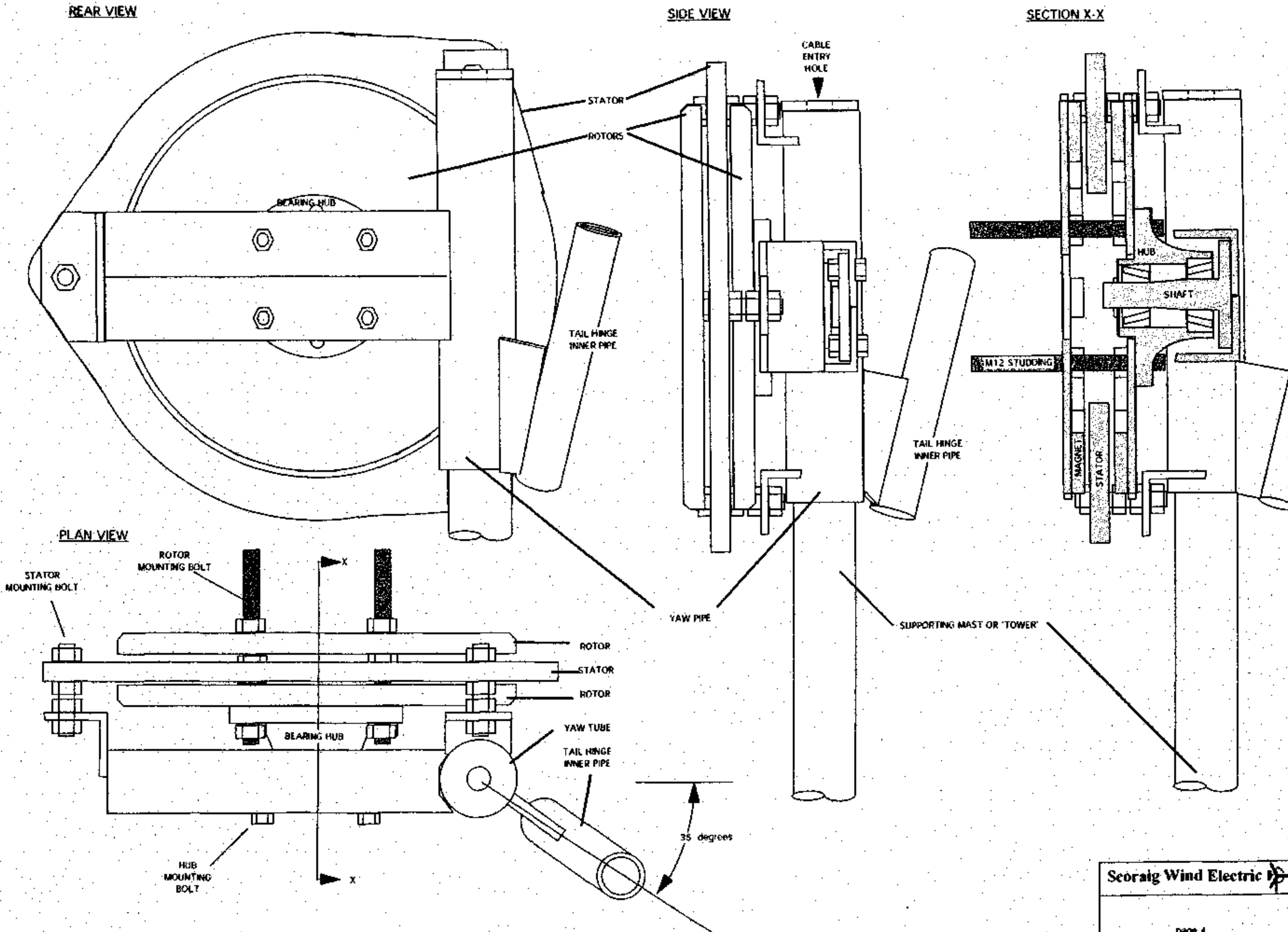
CONSTRUCTION OF BLADES



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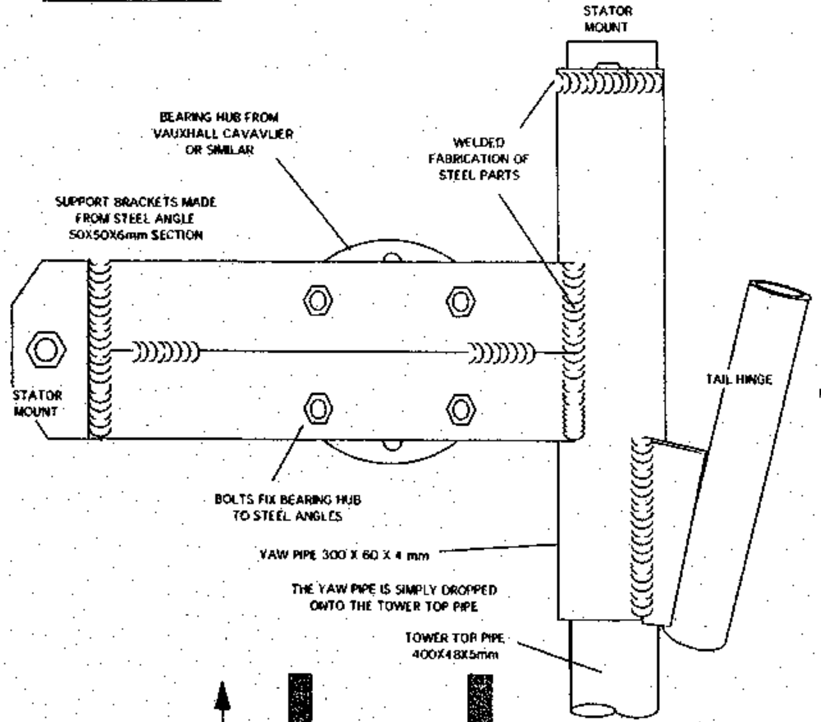
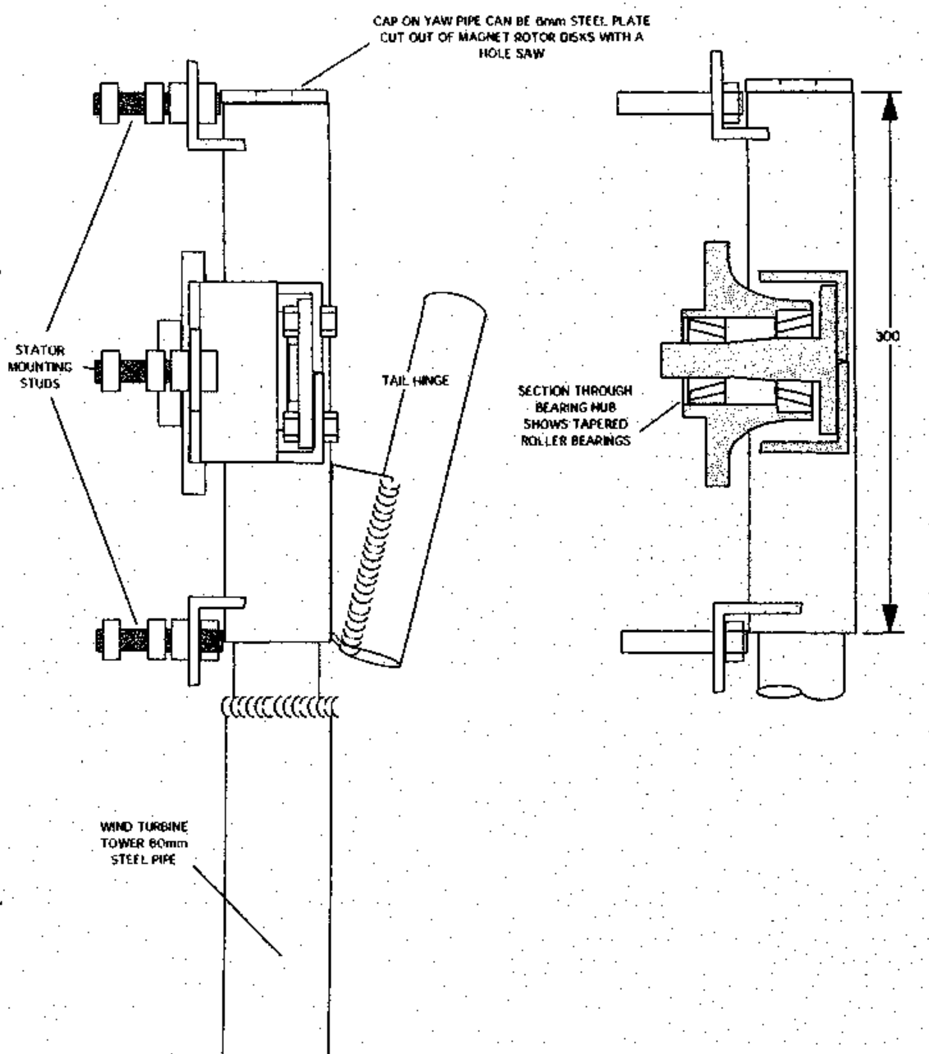
OVERALL VIEW OF ALTERNATOR

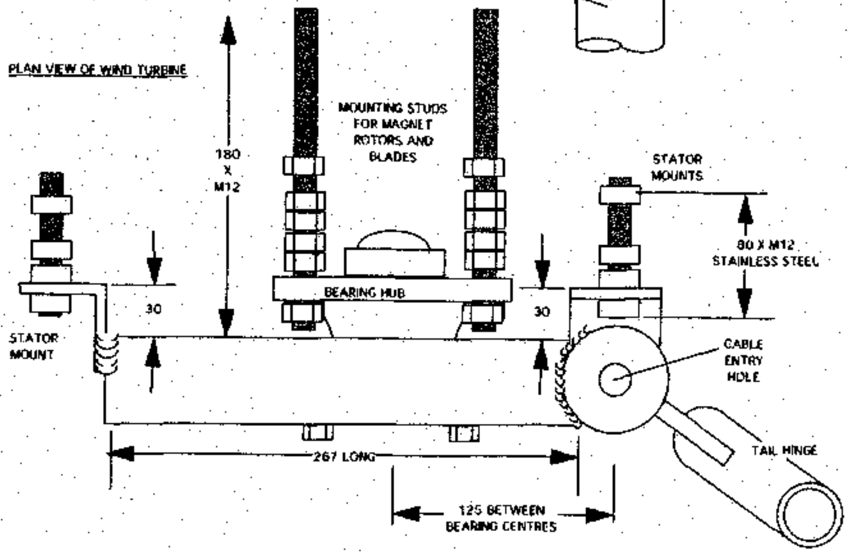
REAR VIEW OF WIND TURBINE



SIDE VIEW OF TURBINE



PLAN VIEW OF WIND TURBINE



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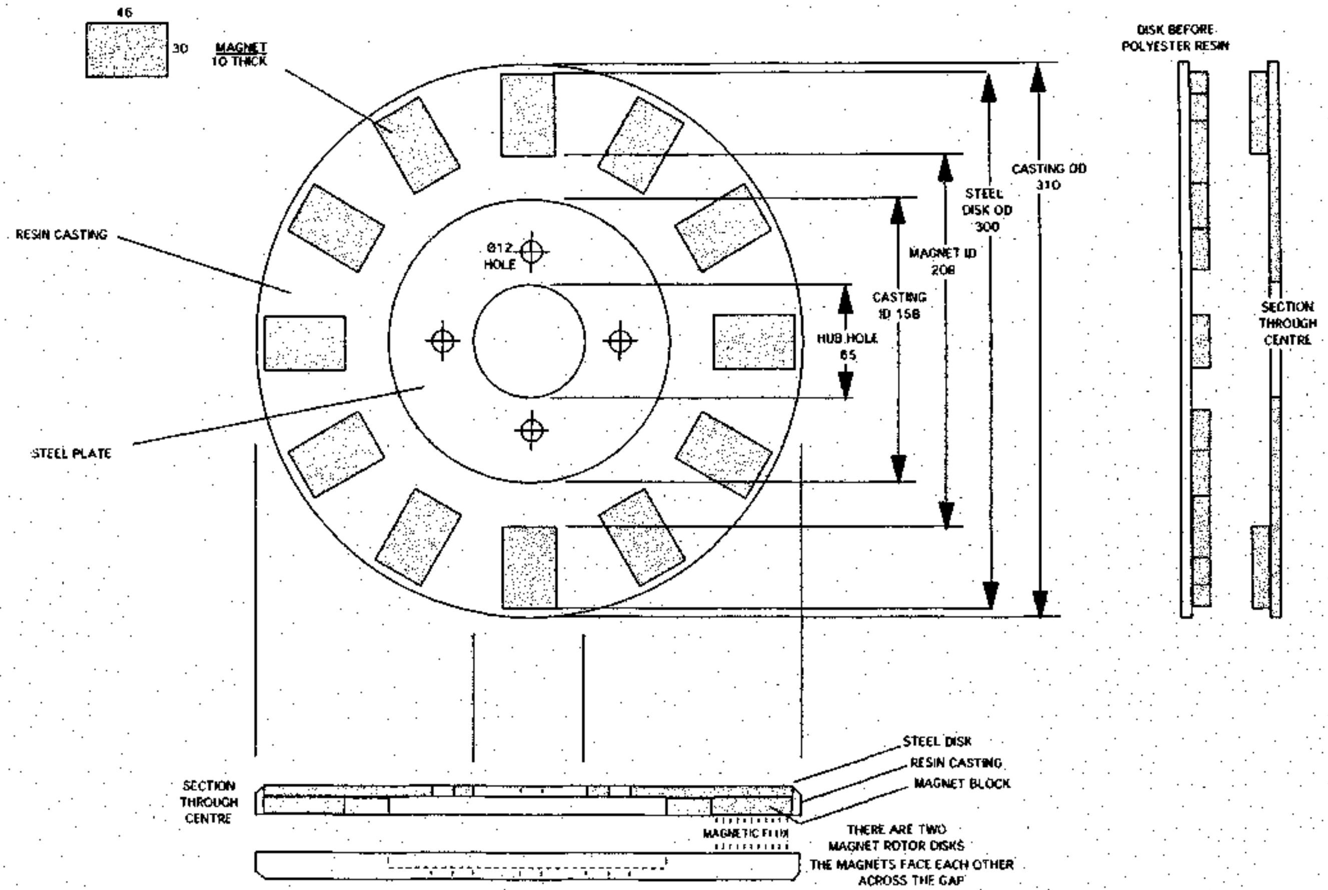
MECHANICAL DETAILS

ROTOR WEIGHT 5 KG EACH

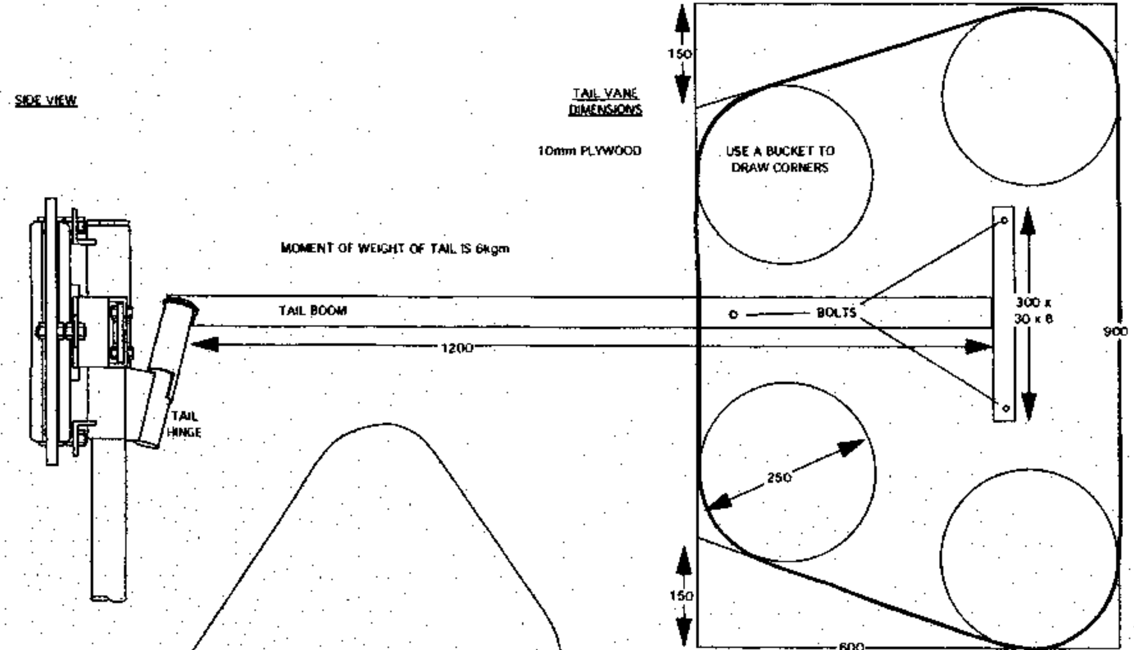


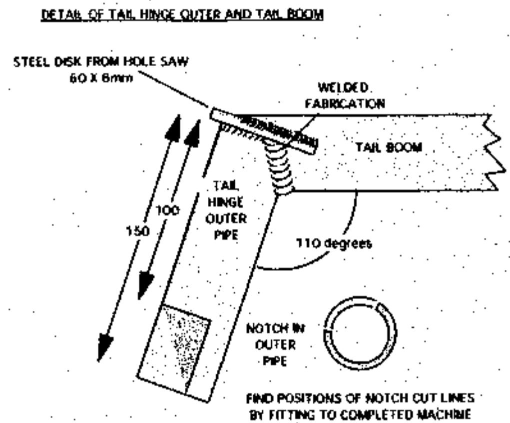
CENTRIFUGAL FORCE ON ONE MAGNET

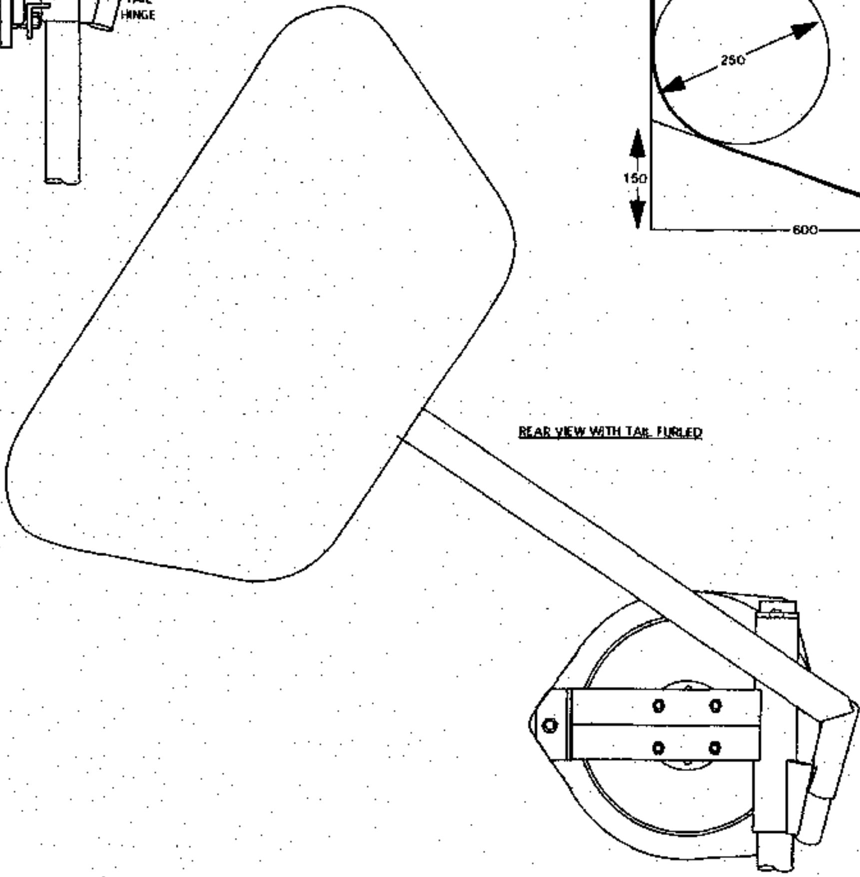
DENSITY OF MAGNET = 7.5g/cc
VOLUME OF MAGNET = 14.1cc
MASS OF MAGNET = 106g

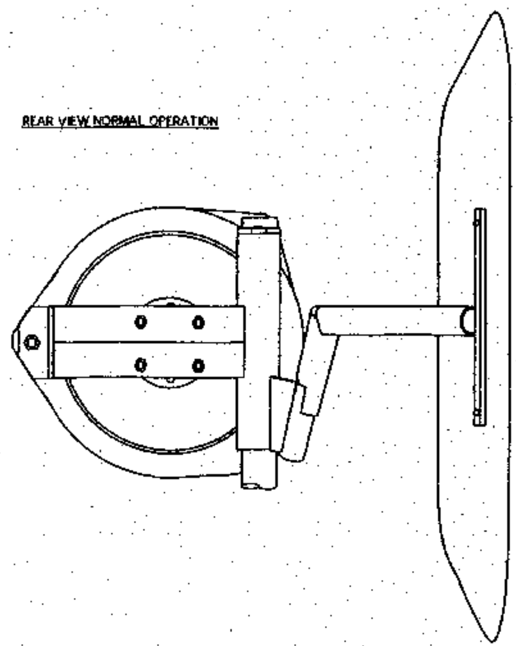
ROTATIONAL SPEED (SAY) 1200 rpm
= 1200/60*2*pi
= 126 radians per second

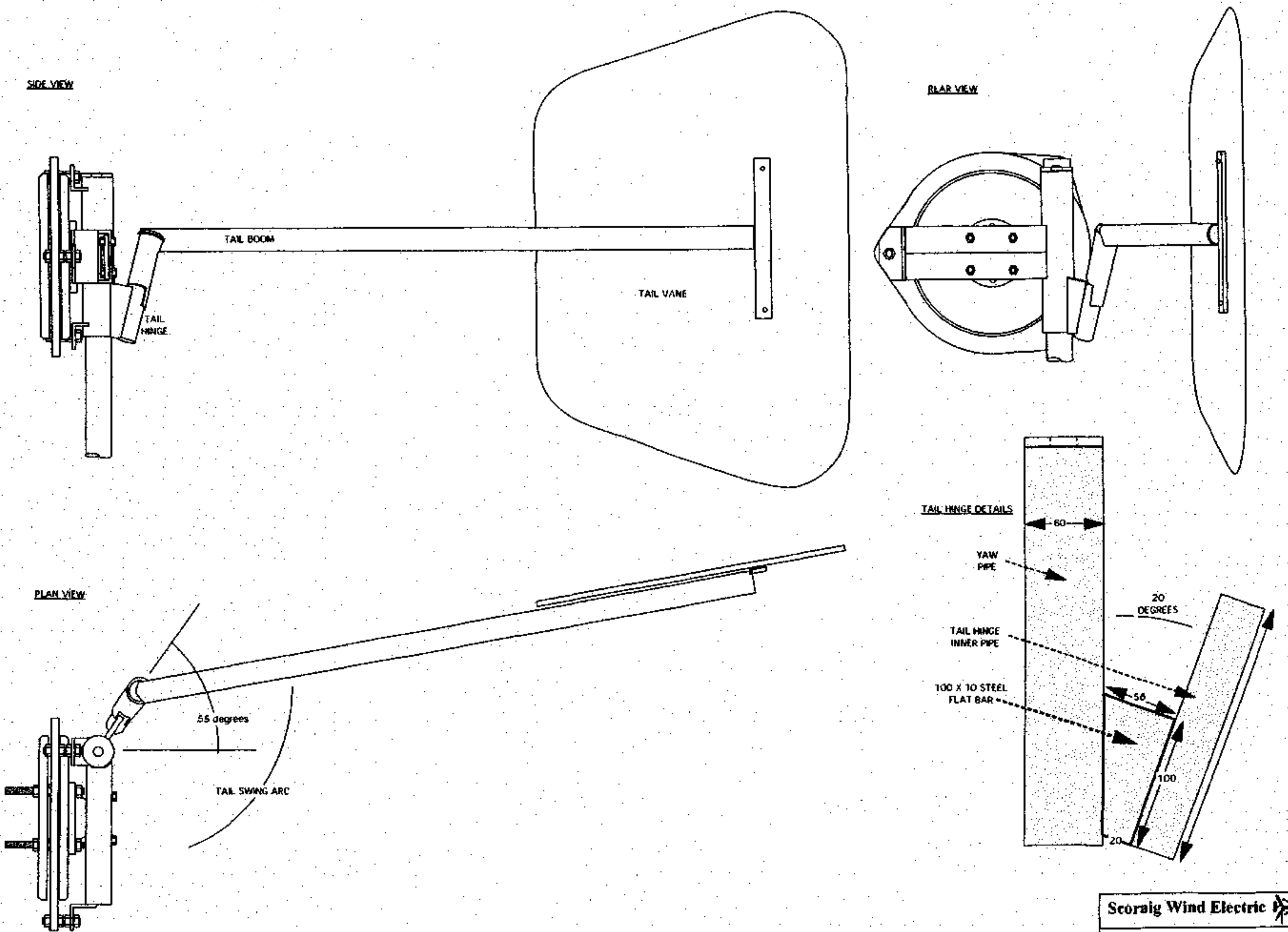
CENTRIFUGAL FORCE = M * r * omega2
= 0.1 * 0.15 * 126 * 126
= 238N = 24.3kg


SIDE VIEW
TAIL VANE DIMENSIONS
10mm PLYWOOD
USE A BUCKET TO DRAW CORNERS
MOMENT OF WEIGHT OF TAIL IS 6kgm
TAIL BOOM
BOLTS
1200
300 x 30 x 6
900
150
150
250
600
TAIL HINGE


DETAIL OF TAIL HINGE OUTER AND TAIL BOOM
STEEL DISK FROM HOLE SAW 60 X 6mm
WELDED FABRICATION
TAIL BOOM
TAIL HINGE OUTER PIPE
150
100
110 degrees
NOTCH IN OUTER PIPE
FIND POSITIONS OF NOTCH CUT LINES BY FITTING TO COMPLETED MACHINE


REAR VIEW WITH TAIL FURLED


REAR VIEW NORMAL OPERATION



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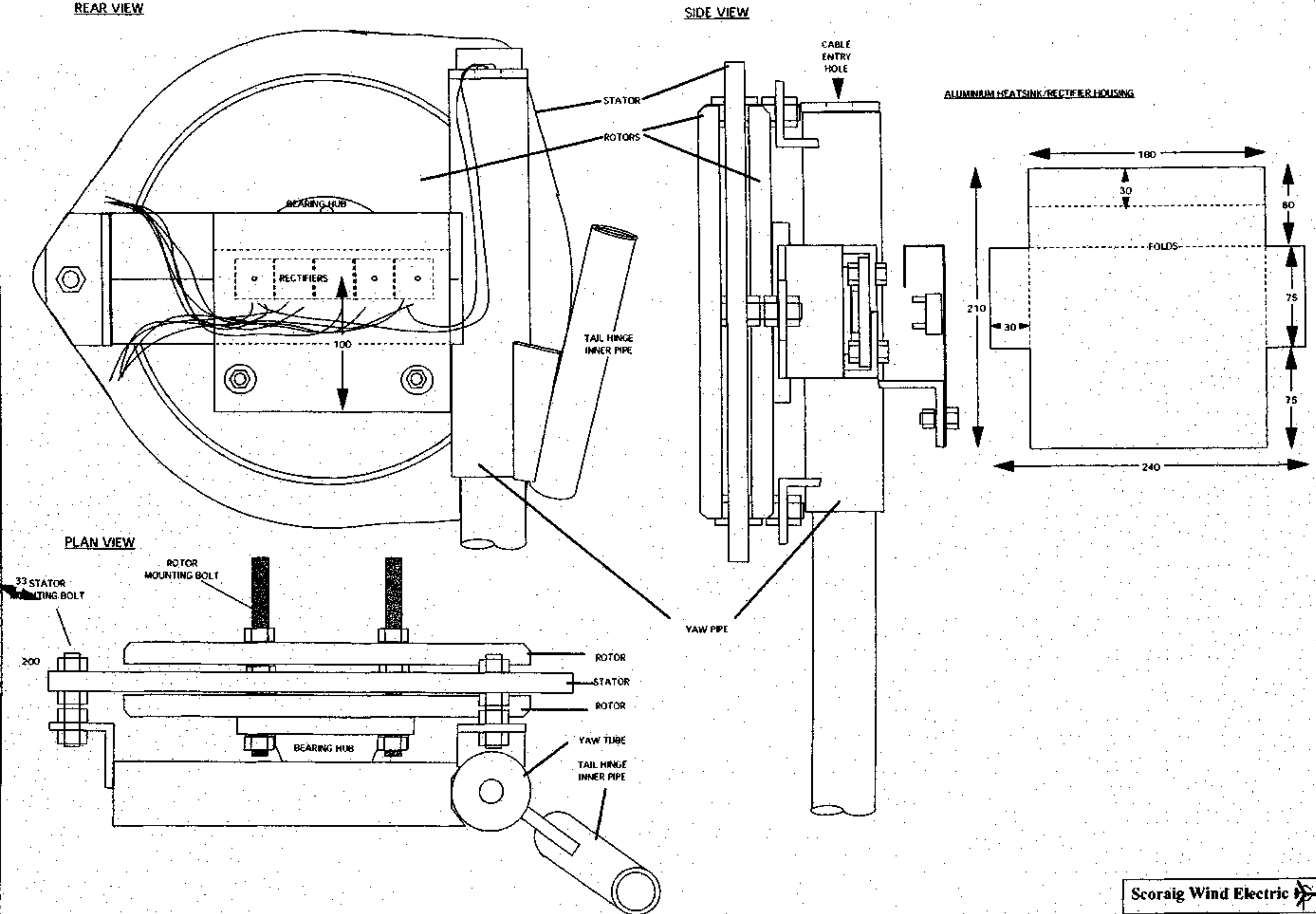

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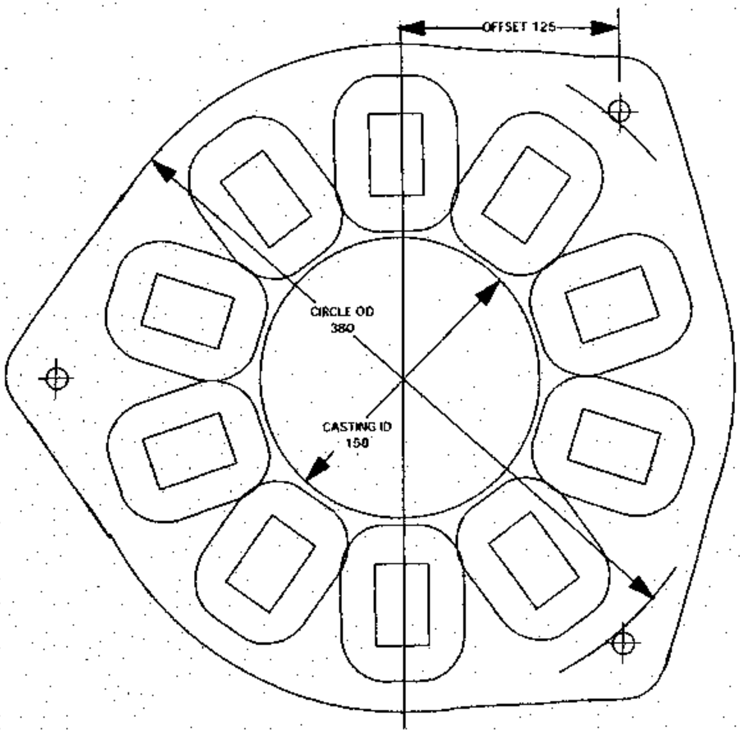
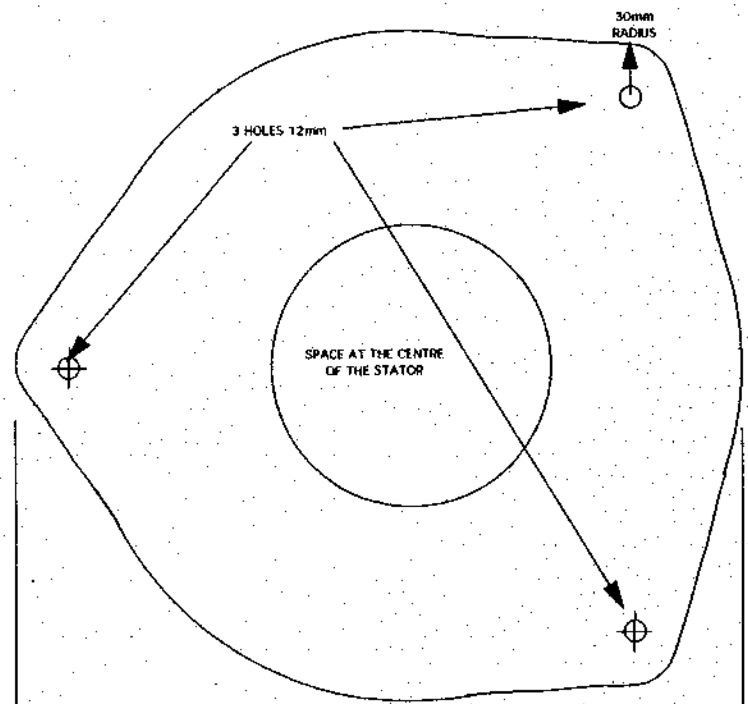
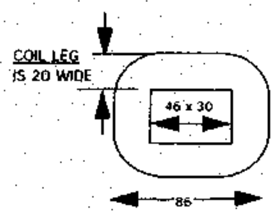
CONSTRUCTION OF RECTIFIER UNIT

STATOR WEIGHT 4.5KG

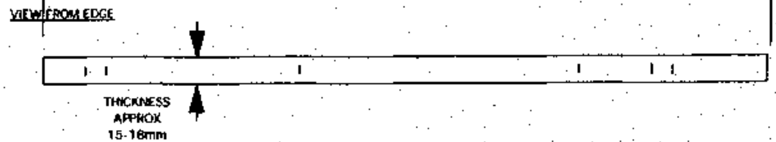




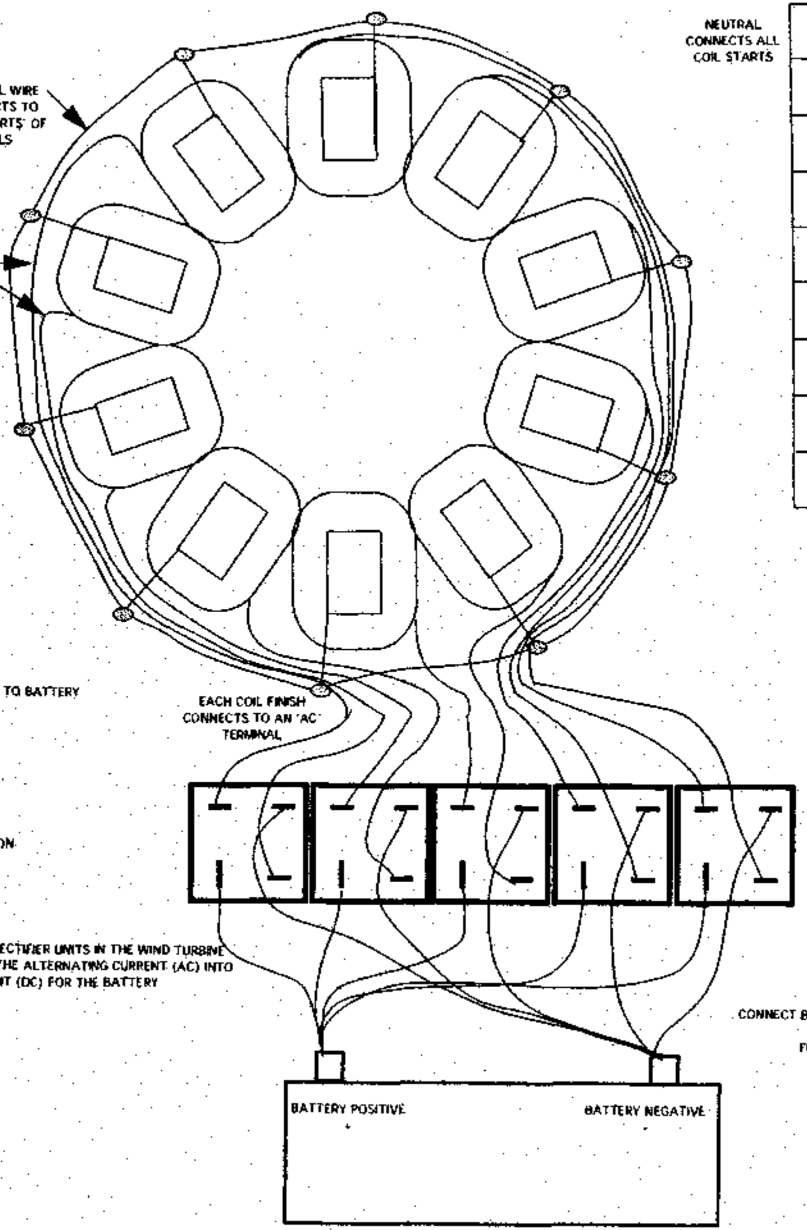


COILS ARE WOUND WITH 90 TURNS OF 1.4mm DIAMETER ENAMELLED WIRE FOR A 12 VOLT BATTERY SYSTEM

FOR 24 VOLTS, USE 180 TURNS OF 1MM DIAMETER
FOR 48 VOLTS USE 360 TURNS OF 0.7MM DIAMETER



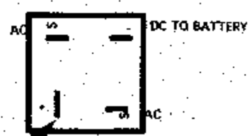
COIL CONNECTIONS



THERE ARE FIVE BRIDGE RECTIFIER UNITS IN THE WIND TURBINE
THE RECTIFIERS CONVERT THE ALTERNATING CURRENT (AC) INTO DIRECT CURRENT (DC) FOR THE BATTERY

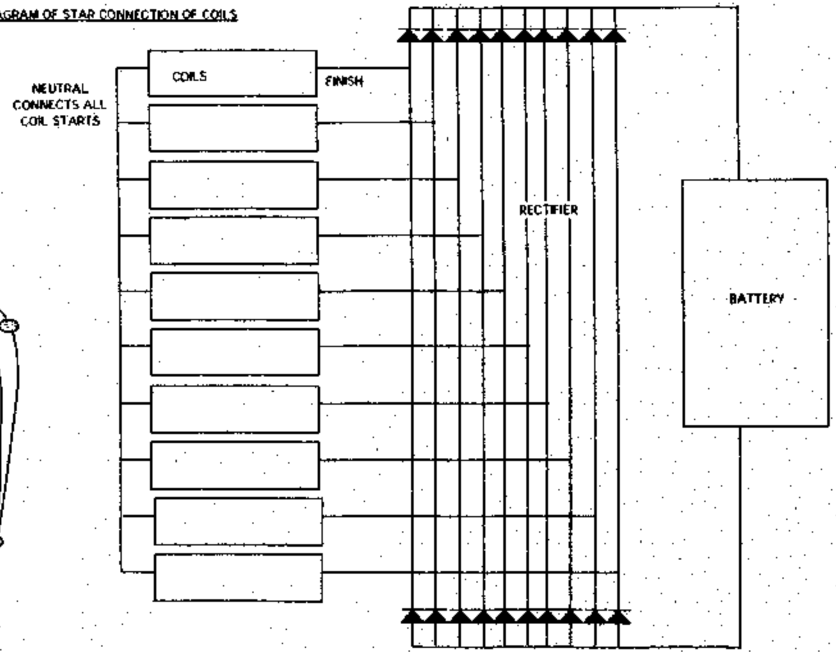
CONNECT BATTERY WITH THICKER CABLE THAN WE USED.
MINIMUM SIZE 6 mm2
FUSE AT BATTERY WITH 40 AMP FUSE

BRIDGE RECTIFIER CONNECTIONS



THE POSITIVE DC CONNECTION IS AT 90 DEGREES TO THE OTHER CONNECTIONS

SCHEMATIC DIAGRAM OF STAR CONNECTION OF COILS



EACH DIODE ALLOWS CURRENT TO FLOW IN THE DIRECTION OF THE ARROW ONLY

Battery Charging

Lead acid batteries should be kept in a charged condition. In the case of a wind powered system, you may have to wait for a wind to charge the battery. But be careful not to discharge the battery too deeply, or to keep it too long in a discharged state, or it will be damaged (sulphated) and become useless. Stop using a battery before it is fully discharged. If there is a problem with the wind generator, then charge the battery from another source within two weeks.

Charging the battery too hard will also damage it. At first, when the battery is discharged, it is safe to use a high current, but later the current must be reduced or the battery will overheat and the plates will be damaged. The best way to fully charge a battery is to use a small current for a long time.

Watch the battery voltage. If the battery voltage is below 11.5 volts, then it is being discharged too much. If the voltage is high (over 14 volts) then the battery charging current is too high. Use less current or more current in the loads to correct these problems. If there is no voltmeter available, then the user should watch the brightness of the lights and follow these rules:-

* Dim lights, mean low battery. Use less electricity!
* Very bright lights mean too much windpower. Use more electricity!

A good way to use more electricity is too charge more batteries in windy weather, perhaps charging batteries from neighbours' houses.

There are simple electronic circuits which can regulate the battery voltage automatically. They are called 'low voltage disconnects' and 'shunt regulators'. If the user is not willing to watch the battery voltage, then it is necessary to fit a disconnect and a regulator.

The diagram shows a simple circuit. I have these in stock for £40 each. But for this machine you would need two of these, and 4 @ 10 amp loads. A good alternative would be a Trace c-40 controller. This has PWM switching on one big load, and it has two battery charging rates.

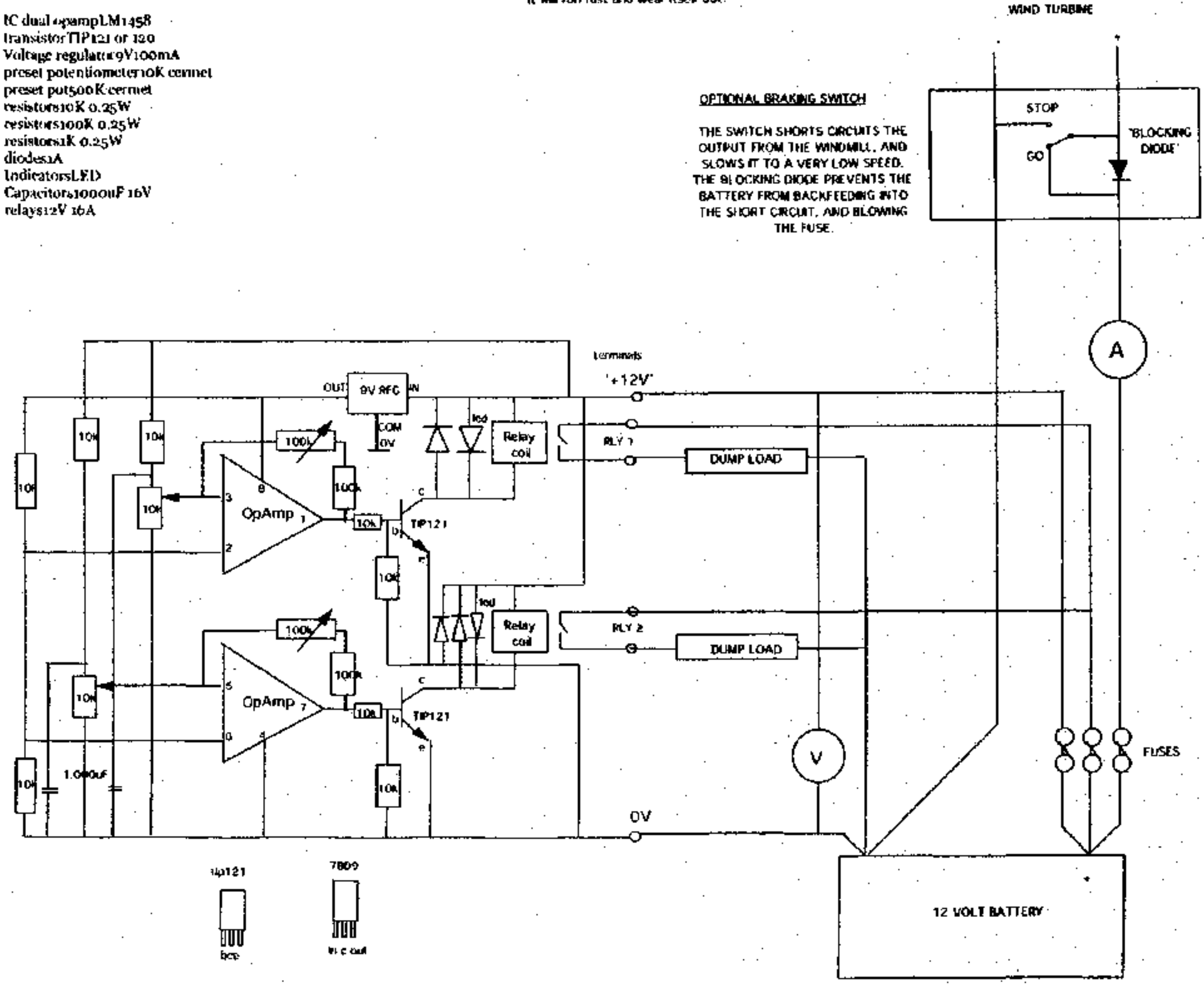
Shunt Regulator

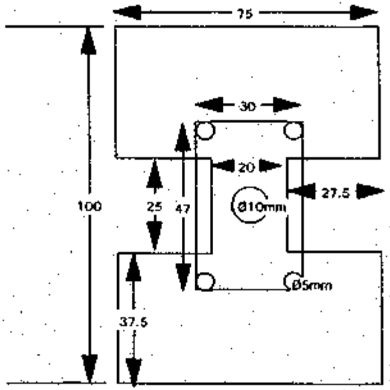
Here is the list of components required

load control cicuit - component purchasing list

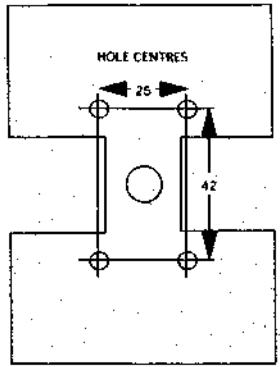
IC dual opamp LM1458
transistor TIP121 or 120
Voltage regulator 9V 100mA
preset potentiometer 10K cermet
preset pot 500K cermet
resistors 10K 0.25W
resistors 100K 0.25W
resistors 1K 0.25W
diodes 1A
Indicators LED
Capacitors 1000uF 16V
relays 12V 16A

The voltage from the wind turbine can rise much higher than 12 volts if it is disconnected forom the battery. Never disconnect the wind turbine from the battery or it will run fast and wear itself out.

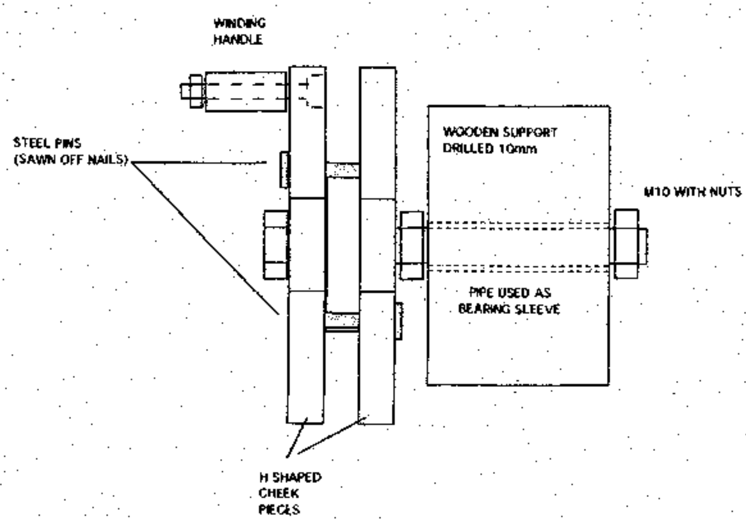


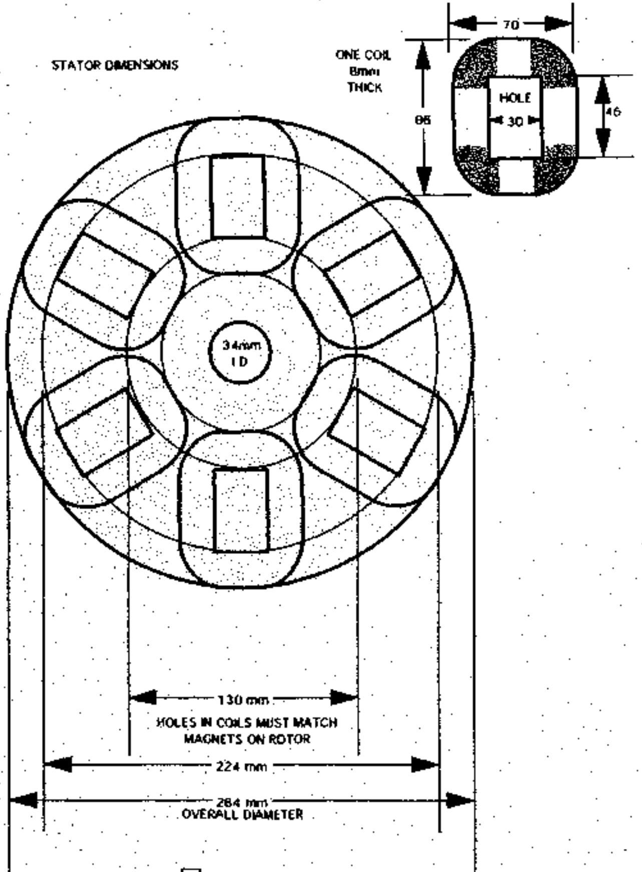


CHEEK PIECE

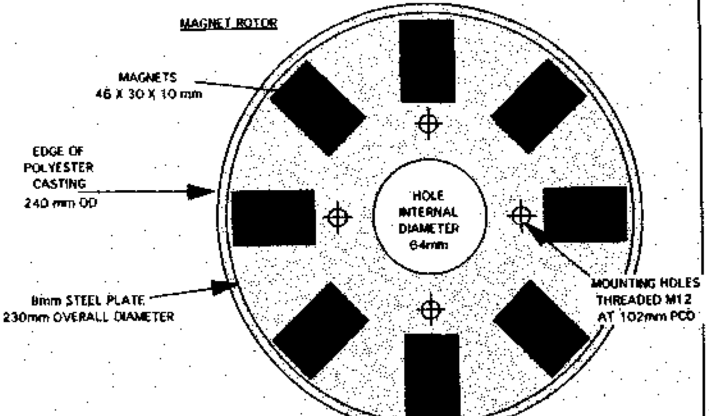


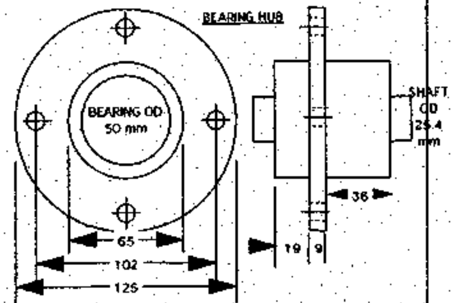
SPACERS 8 AND 13mm THICK

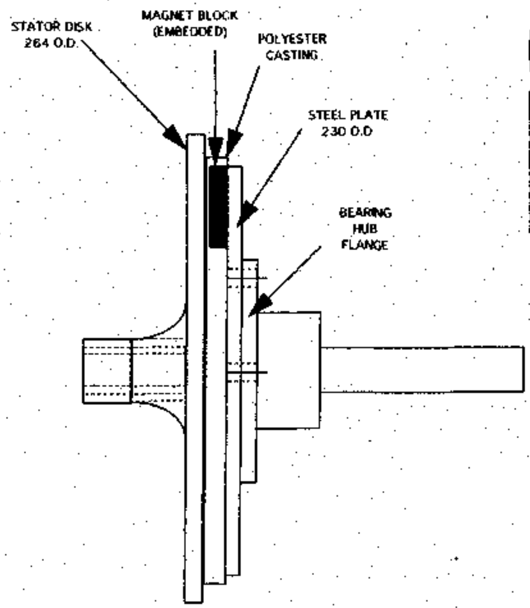


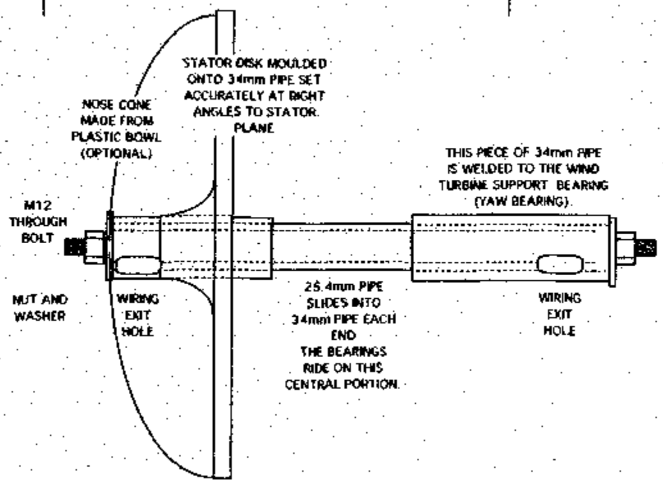


	new single disk of 8
no of magnets	8
magnet length	46
magnet width	30
magnet area	1,380
flux density	340
coil turn length	210
coil csa	160
space factor	0.6
coil turns	150
wire size	0.6
wire size diameter	0.8
wire size AWG	19
coils in series	1
coil in parallel	2
star/delta	1.7
coil turns total	259.5
resistance/coil	0.9
stator resistance	0.9
weight of coil	178
total weight of copper	963
volts(rms)/rpm	0.036
volts DC/rpm	0.050
system voltage	12.0
cut-in rpm	270
desired power output	150
rpm	491
copper + diode loss	157
efficiency	0.49
rotor diameter	1.2
windspeed	11.5
tip speed ratio	2.7
tsr for 3m/s cut-in	5.6









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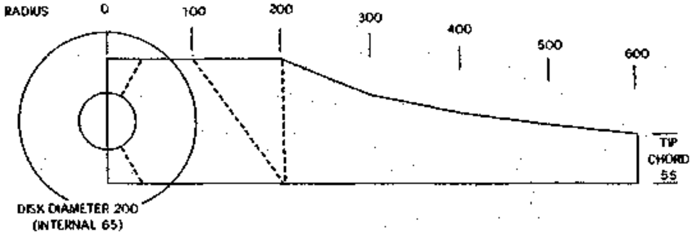
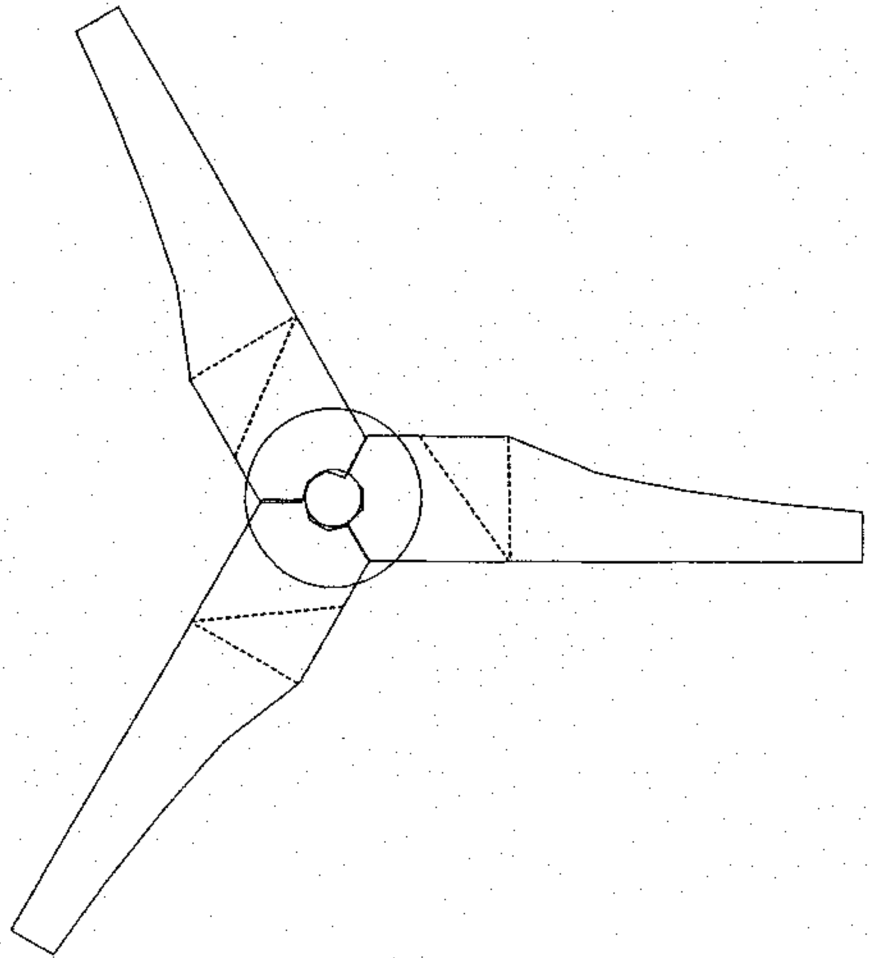
ALTERNATOR FOR
neo 1.2
OCTOBER 2002

station	radius from centre	width	drop	thickness
1	100	140		
2	200	140	37	22
3	300	100	19	14
4	400	80	10	10
5	500	65	6	8
6	600	55	3	6





Blade shape

Any rotor designed to run at tip speed ratio 7 will need to have a similar shape, regardless of size. The dimensions need to be scaled up or down to suit the chosen diameter.

The shape of the blade near the root may vary from one wind turbine to another, even though the blade is designed for the same tip speed ratio. The root of the blade moves slowly and does not have much wind to process, so the shape is less critical than the shape of the outer part of the blade. A strongly twisted and tapered shape is ideal. But in some cases a much less pronounced twist is also successful. I prefer the strong twist and taper because:

it is a) strong

b) good at starting the wind turbine from rest,

and c) I think it looks better.

But in the end it is not going to make a huge difference if the root is a different shape. The blade root shape will probably be determined more by practical issues such as available wood and the details of how to mount it to the alternator than by aerodynamic theory.

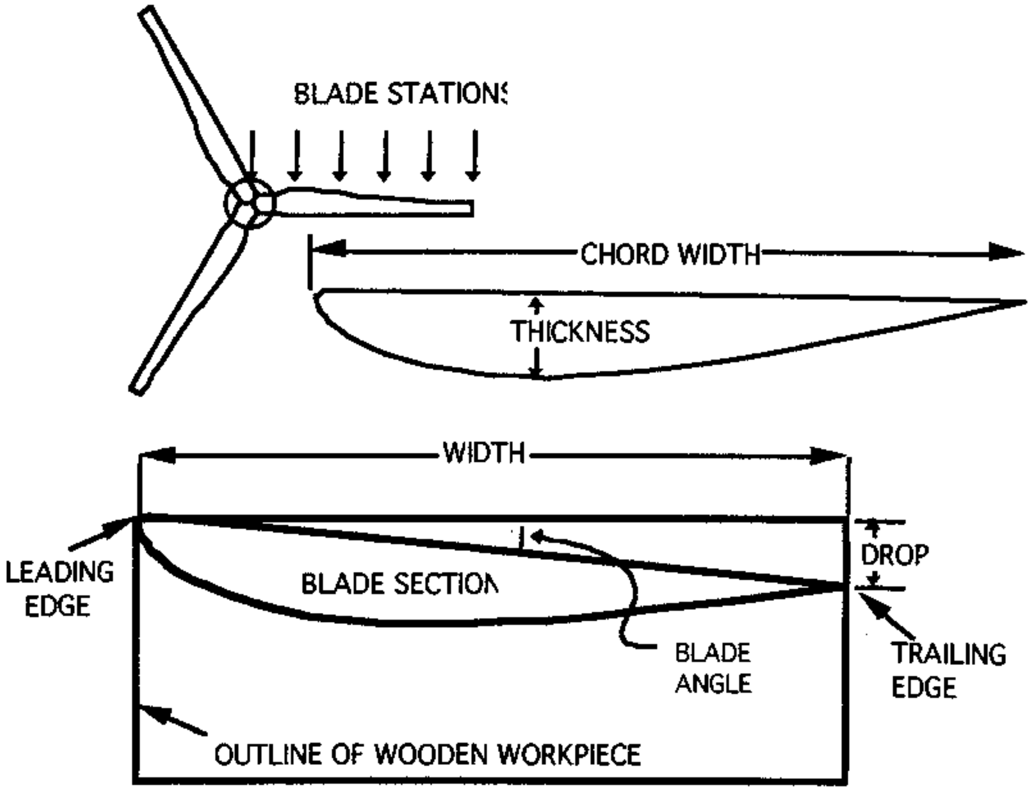


Figure 2: Blade dimensions at one station along its length

The shape will be defined at a series of stations along the length of the blade. At each station the blade has 'chord width', blade angle and thickness as shown in Figure 2. When carving a blade from a piece of wood (a 'workpiece') it is simplest to define the width of the workpiece and also what I call the 'drop'. These measurements will then produce the correct chord width and blade angle. The drop is a measurement from the face of the workpiece to the trailing edge of the blade. Provided that the workpiece is straight and true, this measurement will produce the desired blade angle.

Carving Wooden Blades

The first job is to find suitable timber. Light, straight grained wood is best. It should be well seasoned and free of sap. It is sometimes possible to cut several 'blanks' out of a large plank, avoiding knots. You could glue a piece onto the side of the workpiece to increase the width at the root. Do not increase the length by gluing, as this will weaken the blade. Check for any twist on the face of the workpiece, using a spirit level across the face at intervals along its length. If it is levelled at one point, it should then be level at all points. If the piece is twisted then it may be necessary to use different techniques to mark out accurately the trailing edge (Figure 7).

STEP ONE is to create the tapered shape.

The blade is narrow at the tip and fans out into a wider chord near the root. Table 1 shows the width you should aim for at each station The root stations shapes given for

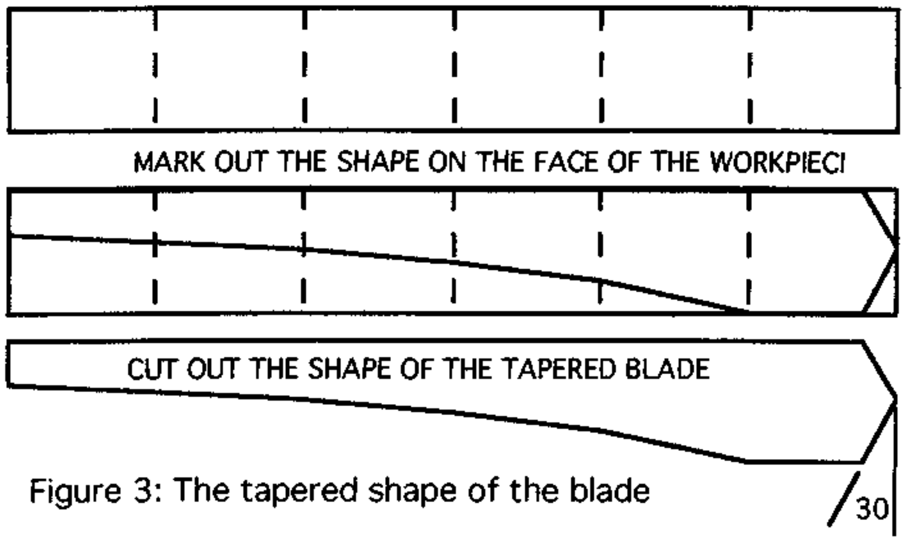


Figure 3: The tapered shape of the blade

different rotor diameters in this book are deliberately different, so as to suit the alternator designs I give in later chapters.

Mark out the stations by measurement from one end of the workpiece (figure 3). Draw a line around the workpiece at each station, using a square. Mark the correct width at each station, and join the marks up with another line. Cut along this line with a bandsaw. Alternatively you can carve away the unwanted wood with a drawknife. Or crosscut it at intervals and chop it out with a chisel. In any case the final cut face should be made neat and square to the rest of the piece.

The root end of the blade will need to be cut to a 120 degree point, so as to meet with the other blades at the centre of the rotor. It does not matter when you cut this. See Figure 6 for dimensions of the angled faces on the 2.4 m diameter rotor. You can scale these for the other sizes.

Blade	1.2m diameter		2.4m diameter		3.6m diameter	
thickness	37 mm thick		37 mm thick		50 mm thick	
station	radius from centre	width	radius from centre	width	radius from centre	width
1	100	140	200	160	300	240
2	200	140	400	120	600	180
3	300	100	600	100	900	150
4	400	80	800	80	1,200	120
5	500	65	1,000	70	1,500	105
6	600	55	1,200	60	1,800	90
Table 1: Step one. Taper the workpiece					Dimensions in mm	

STEP TWO carving the twisted windward face

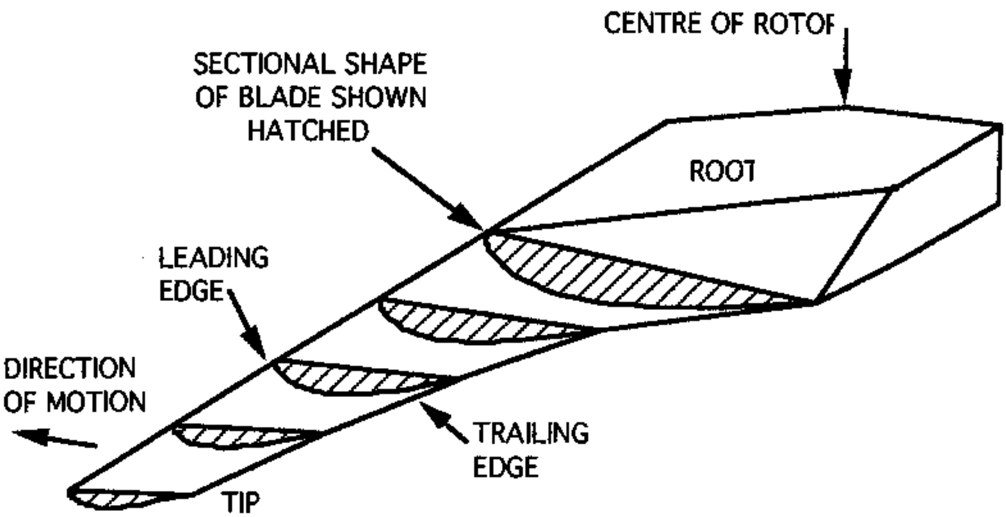


Figure 4: The twisted shape of the blade

The windward face of the blade is flat, like the underside of an aircraft wing. The blade angle needs to be coarser at the root than it is at the tip. Figure 4 shows a series of sectional views of the blade, to indicate how they change in size and angle between the tip and the root of the blade. The angle of the blade changes because the ratio of blade-speed to windspeed becomes less as we approach the centre. This affects the angle of the actual air velocity striking the blade at each station.

In the cases of the 2.4 metre and 3.6 metre diameter rotor, the 'drop' near the root is so large that it exceeds the thickness of the wooden workpiece at the inboard (root) end of the blade. Mark the trailing edge line at the bottom of the workpiece, which is only half of the total drop, in these cases. We use a wooden wedge at the root (Figure 5) to build up the leading edge and allow a large blade angle without needing such a thick piece of wood. The wedge is attached with glue. Leave the gluing on of the wedge until the blade is nearly finished, because its presence makes the blade more difficult to clamp while carving the shape. The wedge will be added in Step five.

Blade	1.2m diameter		2.4m diameter		3.6m diameter	
station	radius from centre	drop	radius from centre	drop	radius from centre	drop
1	100		200	70	300	100
2	200	45	400	25	600	38
3	300	19	600	12	900	18
4	400	10	800	6	1,200	9
5	500	6	1,000	3	1,500	5
6	600	3	1,200	2	1,800	2

Table 2: Step two. The drop — Dimensions in mm

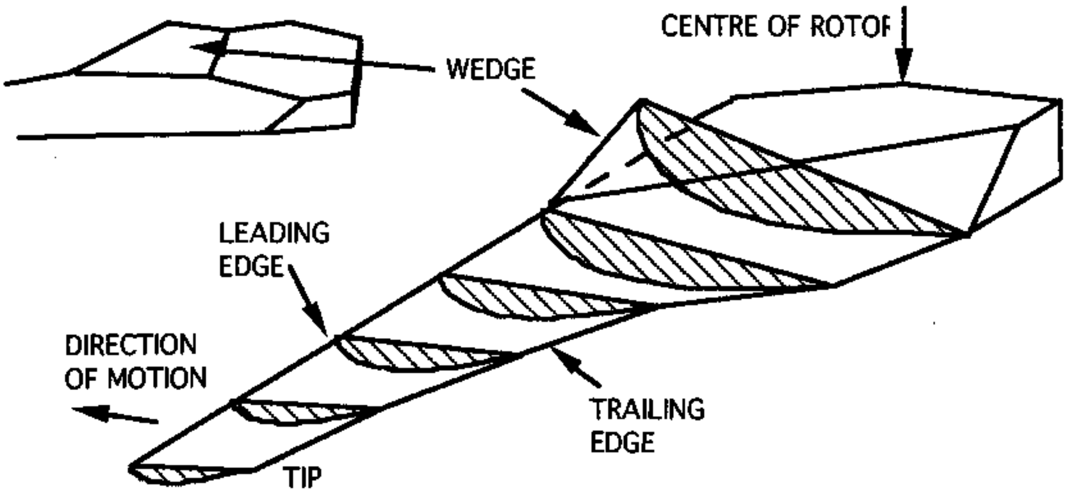


Figure 5: The wedge

Start by marking the stations on the new face cut in Step One (Figure 6). Then mark the drop on each of these new lines, measuring from the face of the wood and marking the position of the trailing edge at each station. Join these marks to form the line of the trailing edge. The leading edge is the other corner of the workpiece (top left in the figures

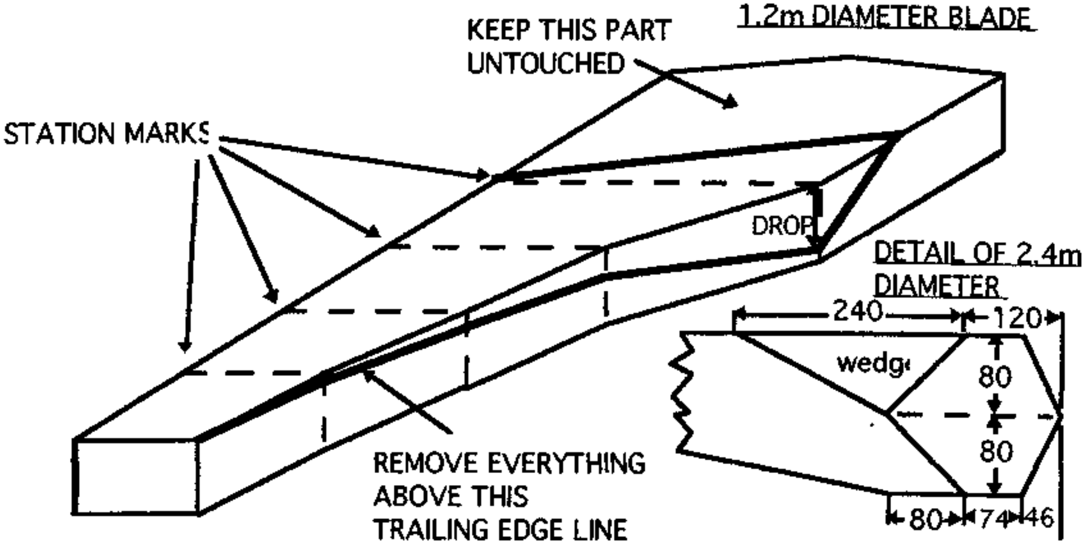


Figure 6: Marking out the trailing edge (1.2 m diameter)

Remove all the wood above this line, so that you can place a straight edge between the leading and trailing edges. In this way you will be forming the twisted windward face of the blade. I use a drawknife and a spoke-shave to do the inner part and a plan is useful on the straighter part. You can use a sander if you prefer. Take care to be precise in the outer part near the tip where the blade angle is critical. Do not remove any of the leading edge, but work right up to, so that the angled face starts right from this corner of the wood.

Leave the blade root untouched, so that it can be fitted into the hub assembly. The hub will be achieved by clamping the blades between two plywood disks (see later). The carving of the windward face ends with a ramp at the inboard end as shown in the figure. This ramp is guided by lines, which meet at a point just outside the hub area. In the case of the 1.2m diameter rotor, the line runs at 45 degrees across the face. For the larger blades the line has two legs – one for the wedge and one for the ramp. See the detail sketch of the 2.4m diameter rotor blade.

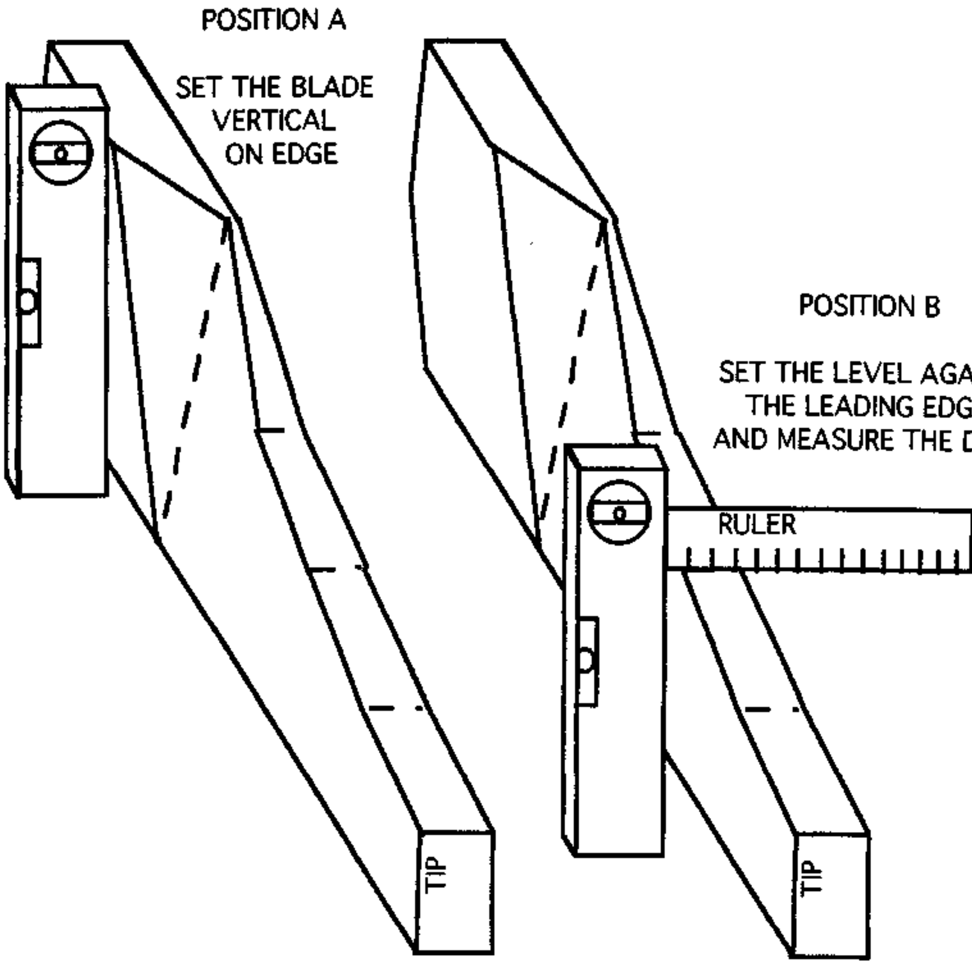


Figure 7: Checking the drop with a level

If in doubt about the accuracy of the blade angle, use a spirit level to check the drop as shown in Figure 7. First use the level to set the blade root vertical (or horizontal if you prefer). At each station, place the level against the leading edge and check the drop between the level and the trailing edge. When measuring the drop, make sure that the level is vertical (or horizontal if appropriate). If the drop is too large or small, adjust it by shaving wood from the leading or trailing edge as required.

STEP THREE carving the thickness

Blade	1.2m diameter		2.4m diameter		3.6m diameter	
station	radius from centre	thickness	radius from centre	thickness	radius from centre	thickness
1	100		200	36	300	53
2	200	22	400	25	600	37
3	300	14	600	13	900	20
4	400	10	800	10	1,200	15
5	500	8	1,000	8	1,500	13
6	600	6	1,200	7	1,800	11

Table 3: Step three. Blade thickness

Dimensions in mm

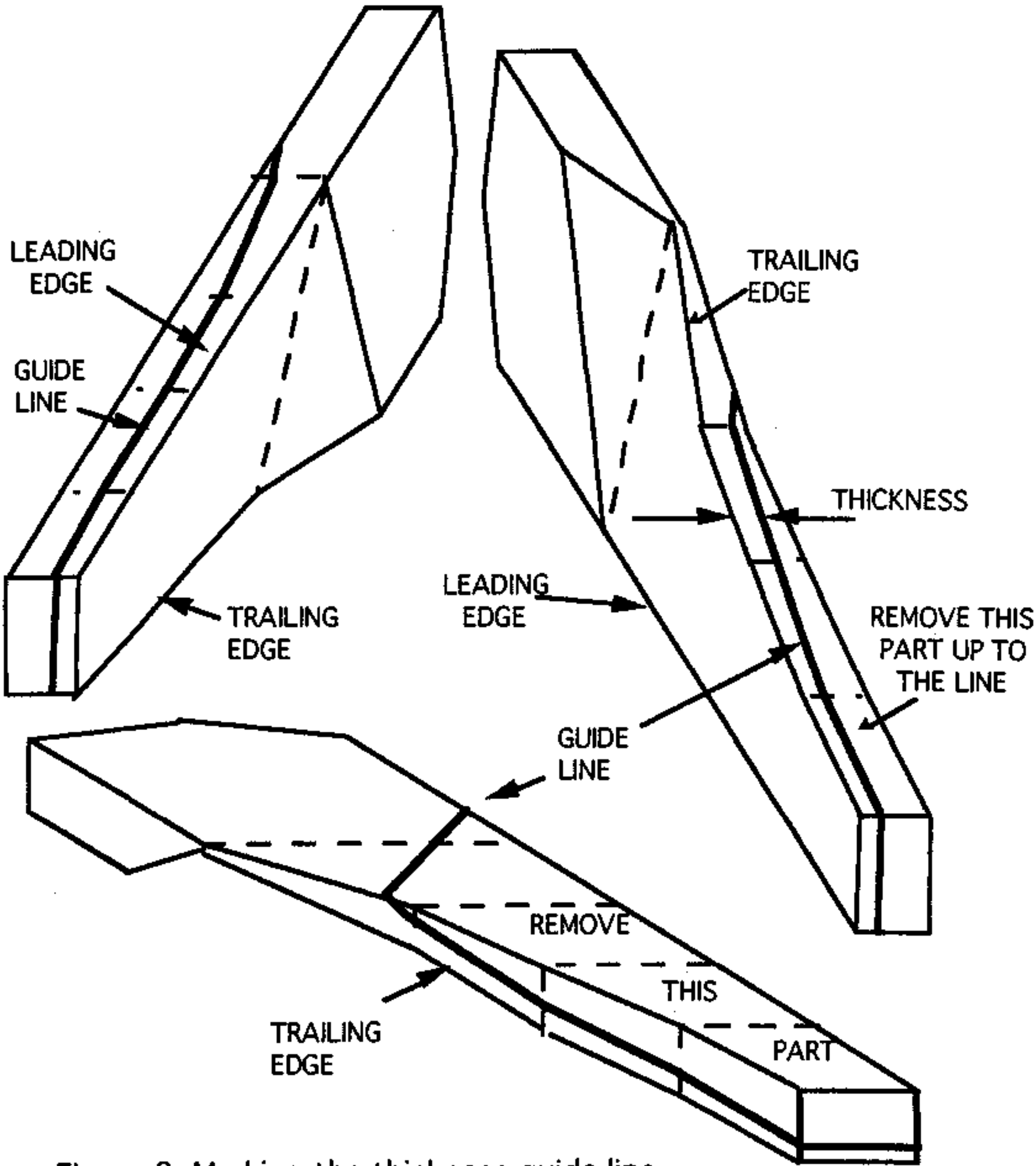


Figure 8: Marking the thickness guide line

Table 3 shows the thickness of the blade section. At each station, measure the appropriate thickness from the windward face, and make a mark. Join the marks to form a line. Do this at both the leading and trailing edges (Figure 8). These lines will guide you as you carve the section, to achieve the correct thickness. Carve the back of the blade down to these lines.

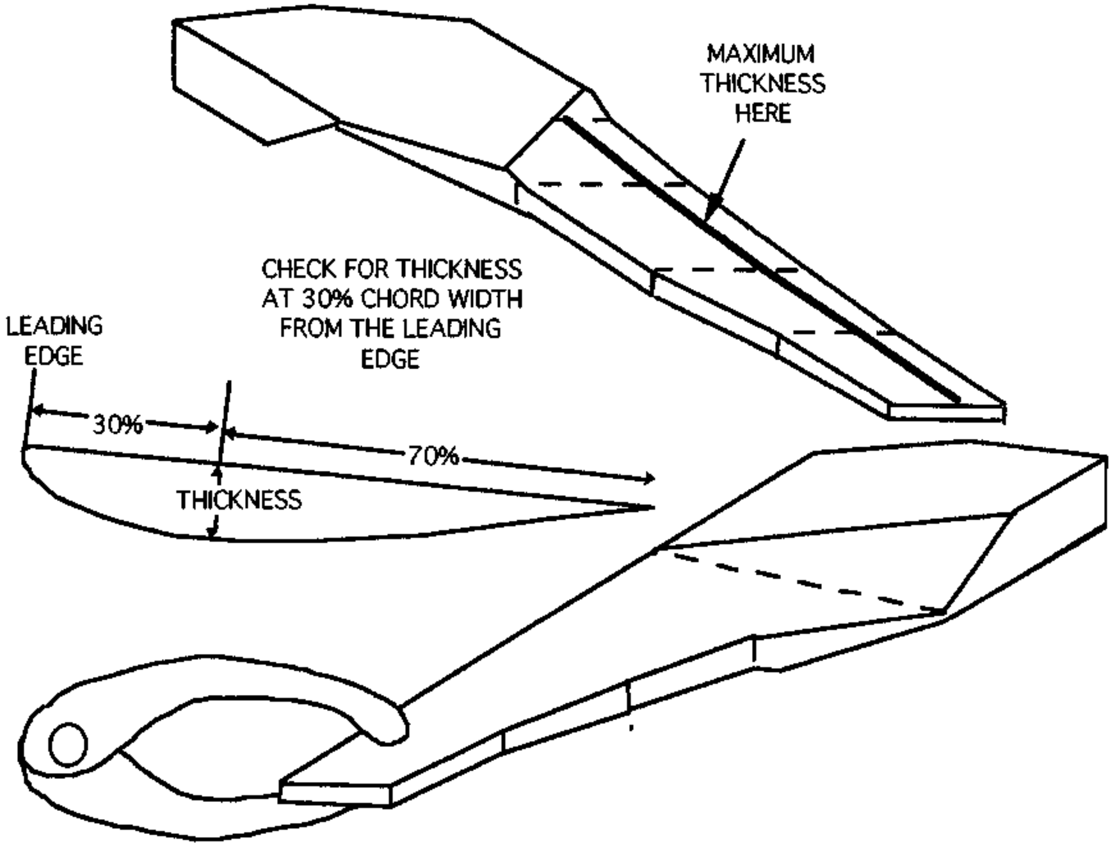


Figure 9: Checking the thickness with callipers

As you approach the lines themselves, you should begin to check the thickness with callipers at each station (Figure 9).

Both sides of the blade should now be flat and parallel to each other, except at the inner part where this is not possible, because the workpiece is not thick enough to allow full thickness across the whole width. In this area you need not worry about the part nearer to the tailing edge, but try to make the faces parallel where you can. The final blade section will only be full thickness along a line that runs about 30% of the distance from leading to trailing edges. See Figure 9.

STEP FOUR Carve the curved shape on the back of the blade

The blade is nearly finished now. The important dimensions, width, angle and thickness are all set. It only remains to give create a suitable airfoil section at each station. If this

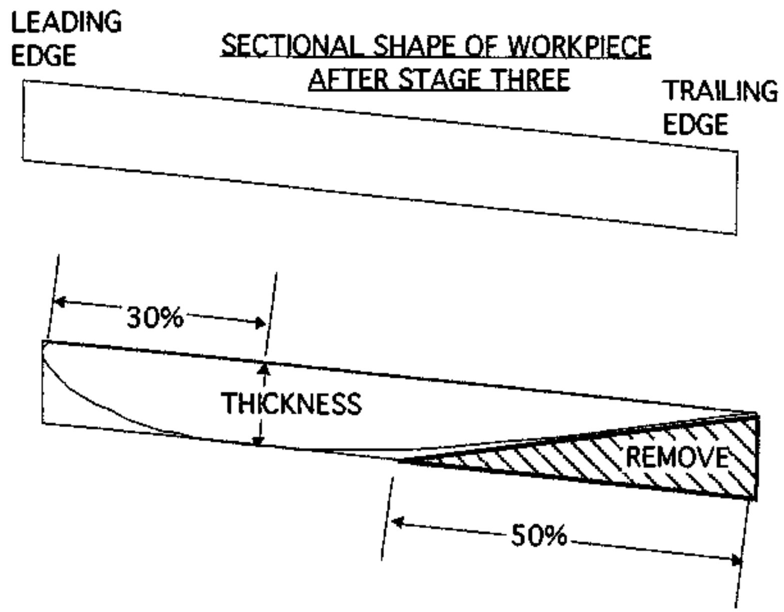


Figure 10: Feathering the trailing edge

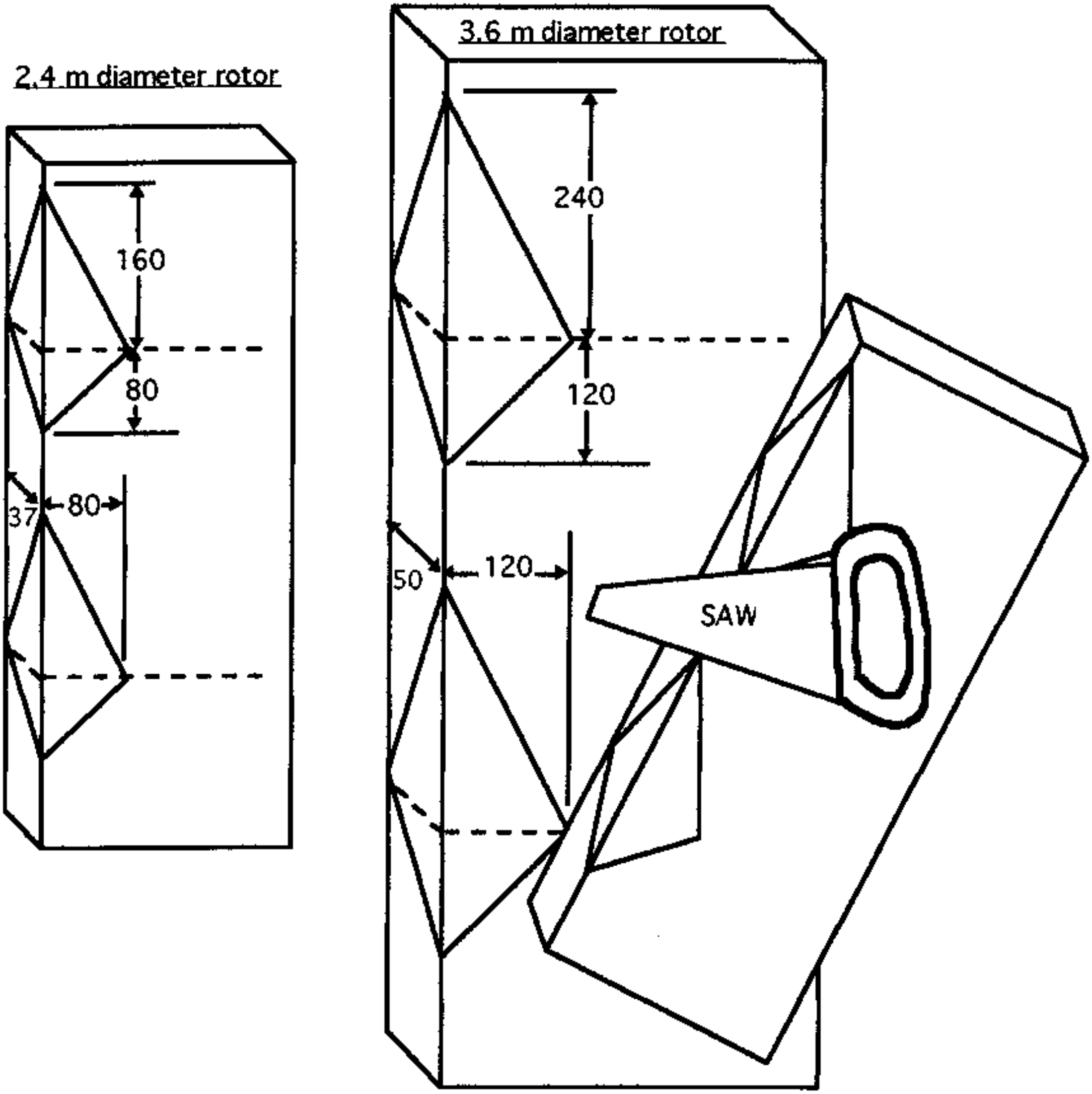
is not done, the blade will have very high drag. This would prevent it from working well at high tip speed ratio. The first step is to make a feathered trailing edge (Figure 10). Take great care to cut only the back of the blade. Do not touch the front face. You carved the front face in Step Two.

Carve off the part shown hatched in the figure, between the trailing edge and the middle of the blade width. This will form the correct angle at the trailing edge. If in doubt, draw two lines along the back of the blade, at both 30% and 50% width measured from the leading toward the trailing edge. The 30% line represents maximum thickness and should not be carved down further. The 50% line is to guide you in carving the feathered trailing edge. When you have finished, it should be possible to place a straight edge between this line and the trailing edge. The trailing edge should be less than 1 mm thick.

Finally, the blade has to be carved into a smoothly curving shape according to the section shown in Figure 10. It is hard to prescribe exactly how to produce the curve. The best description is simply 'remove any corners'. As you remove corners, you will produce new corners, which in turn need to be removed. Remove less wood each time. Take care not to remove too much wood. Do not remove wood from the thickest point. Take care not to produce a corner at this thickest point.

STEP FIVE Cutting out and gluing on the wedges (2.4 and 3.6 m diameter rotors)

Figure 11 shows the dimensions of the wedges for the two larger rotors. The simplest way to produce them is to cut them from the corners of blocks of wood as shown.



Choose a clear part of the block and draw two lines at right angle to the corner, shown dashed in the figure. Measure out the dimensions shown in mm, and draw the angled lines, marking the cuts you will make. To cut out the wedges, place the block of wood in a vice with one line vertical. Align the blade of the saw carefully so that it lines up with both lines demarcating the cut. Then saw out the wedge.

The position to glue the wedge on is shown in Figures 5 and 6.

STEP SIX Assembling the rotor hub.

If the roots of the blades have not been cut to a 120 angle already, then this is the time to cut them. Cut out two disks of plywood

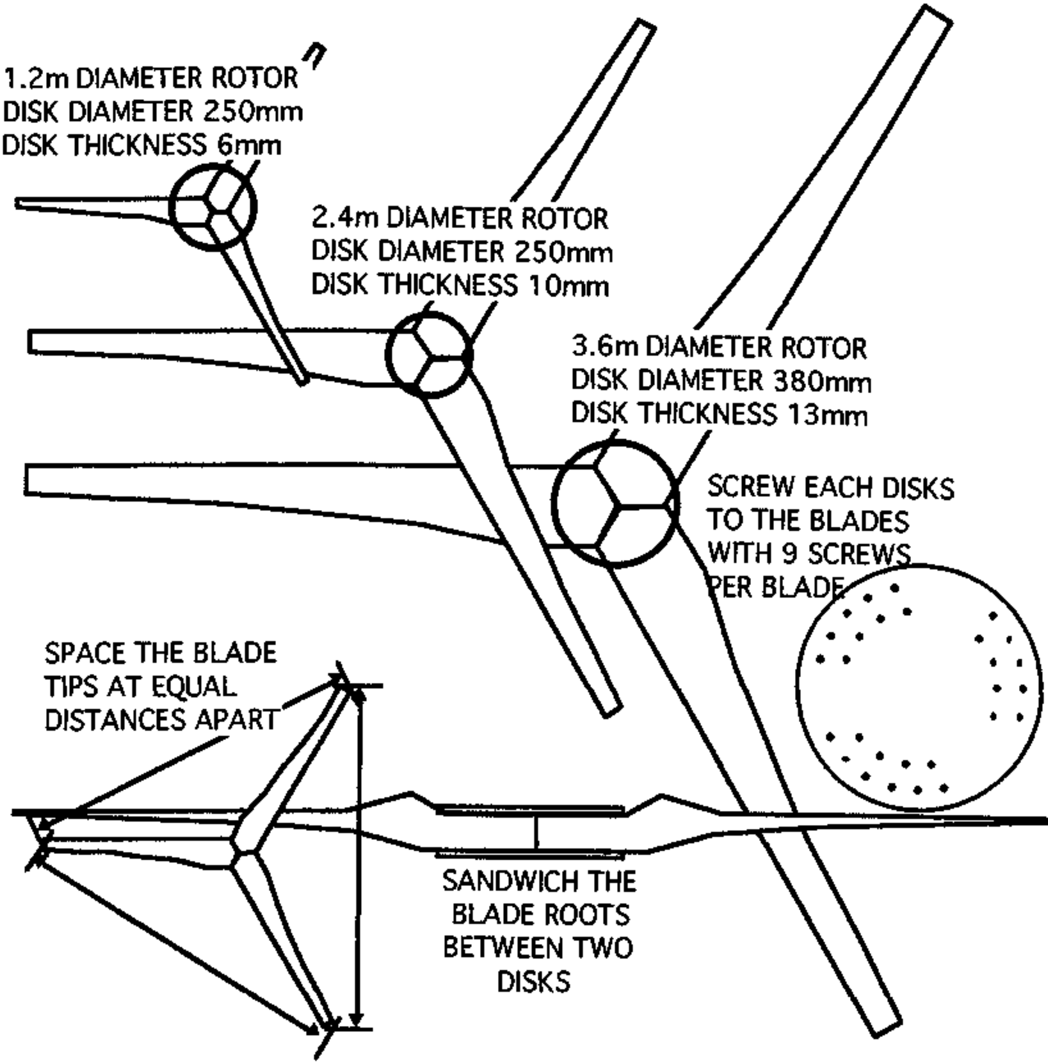


Figure 12: Assembling the rotor blades with plywood disks

Drill each disk with 18 neatly spaced screw holes as shown. Avoid drilling screw holes on the diameter of the mounting bolts (see alternator design). Countersink these holes. Paint the blades and disks with before assembly.

Take care that the blades are positioned with equal spacing between the tips. Place a disk at the exact centre (measuring from the tips). Screw it on with 9 screws per blade. Turn the assembly over and repeat.