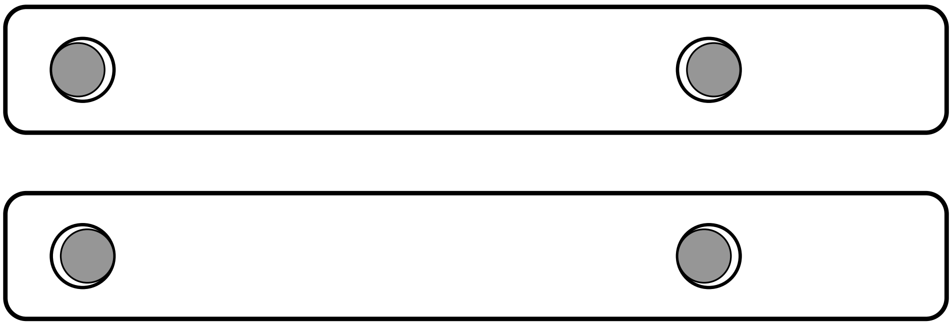
1 (a) 'Safety factor' is the ratio of material strength to working stress. 'Safety margin' is the difference between the material strength and working stress. For the lock barrel and shackle; the failure occurs if the exterior shackle arm-to-arm distance is greater than the exterior barrel hole-to-hole distance or if the interior shackle arm-to-arm distance is less than the interior barrel hole-to-hole distance.



Hence working stress is equivalent to the nominal interior/exterior distance and material strength is equivalent to the maximum exterior or minimum interior distance. [20%]

(b) Nominal safety factor $= \dfrac{\text{maximum nominal exterior shackle distance}}{\text{nominal exterior shackle distance}}$

$= 110 / 109 = 1.009$

Worst case safety factor $= \dfrac{\text{minimum exterior hole distance}}{\text{maximum exterior shackle distance}}$

$= (100 - 0.5 + 10 - 0.1) / (100 + 2.0 + 10 + 0.1) = 0.976$

Note: answers can vary depending on the nominal distance chosen, i.e. centre-centre pitch or half-pitch. [20%]

(c) Spreadsheet below shows calculation of safety margins.

					μ	σ	variation		
ASSUMING	6σ								
			barrel	hole	10.00	0.03	0.10		
				centres	100.00	0.17	0.50		
			shackle	arm	9.00	0.03	0.10		
				centres	100.00	0.67	2.00		
			var	bend	μ	σ	z	p(m<0)	%
Safety Margin	(c) (i)	(100+10)-(100+9)	0.67	0.00	1.00	0.69	-1.45	0.0733	14.66
	(c) (ii)	(100+10)-(100+9)	0.67	1.00	1.00	0.69	-2.90	0.0018	0.37

Percentage failure with no bending is 14.7% and with bending is 0.4%. [40%]

(d) Spreadsheet below shows calculation of revised safety margin.

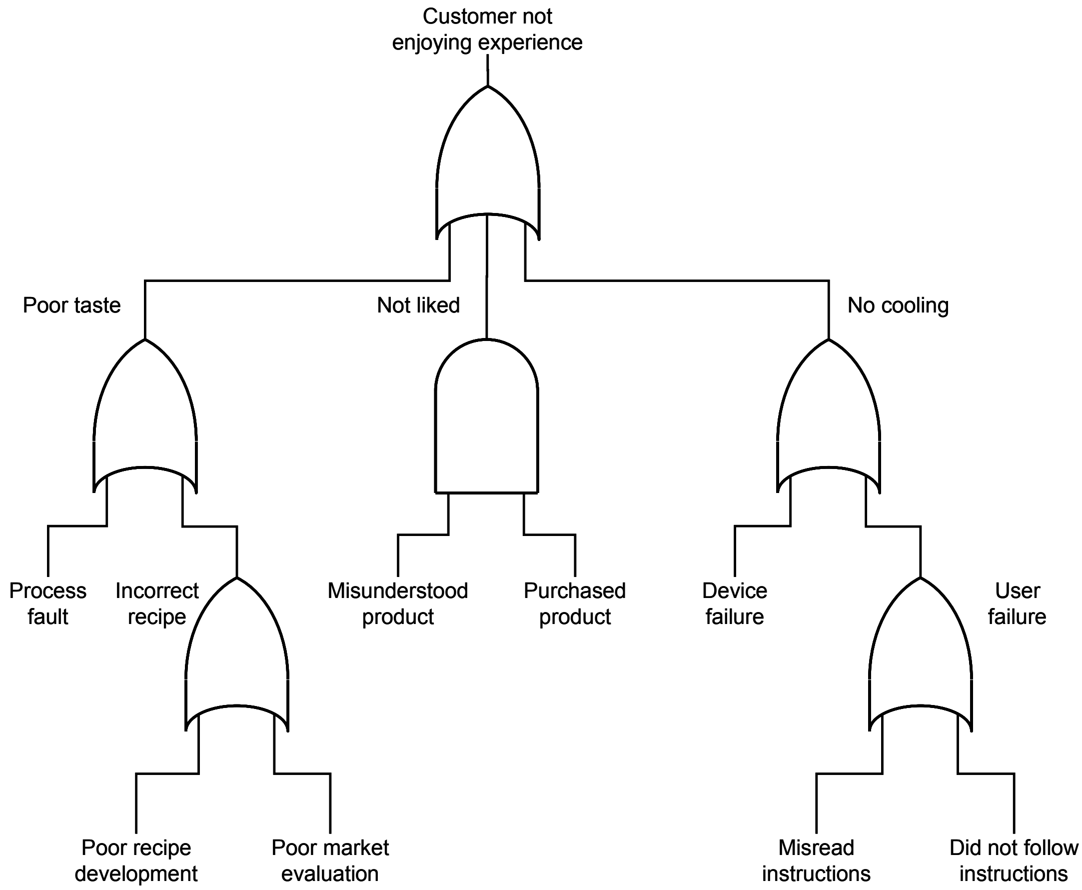
			var	bend	μ	σ	z	p(m<0)	%
Safety Margin	(d)	(100+10)-(100+9)	0.51	1.00	1.00	0.54	-3.72	0.0001	0.020

Variation of shackle width allowable for failure with bending of 0.02% is 1.5 mm. [20%]

2 (a) Key requirements might include:

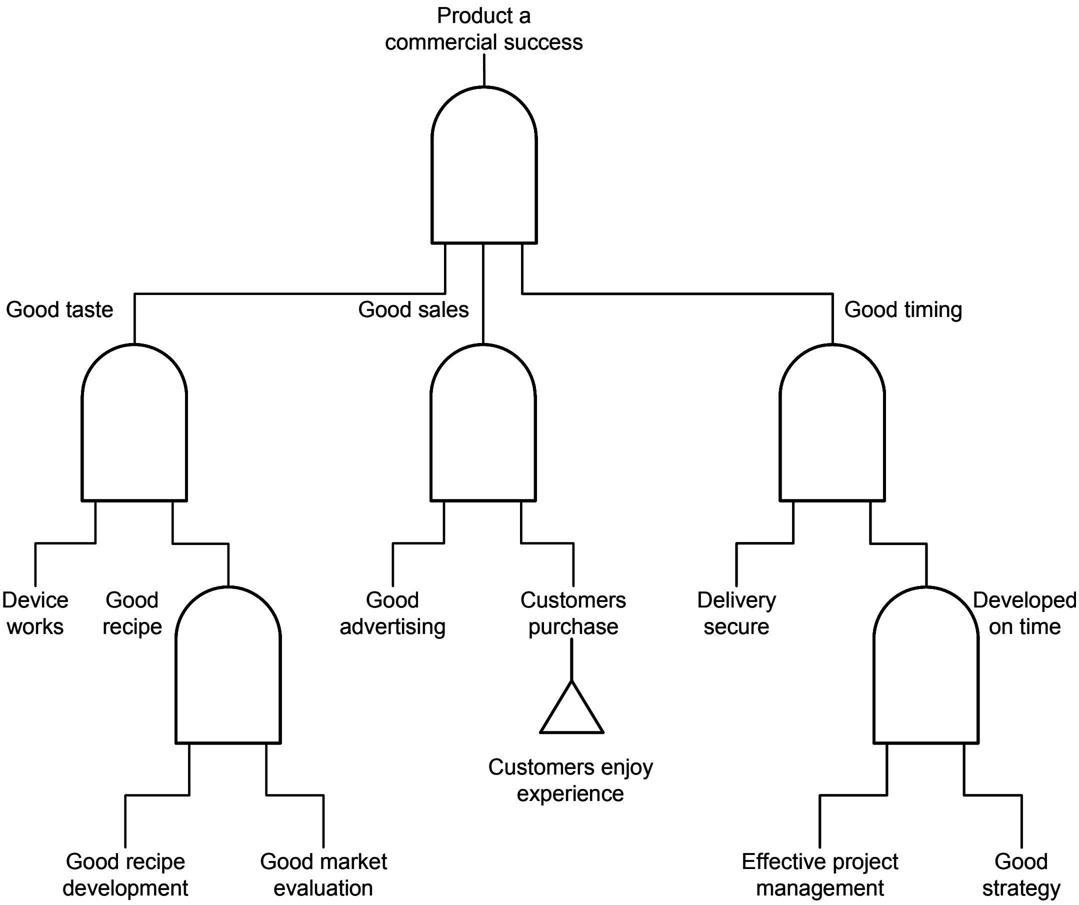
1. Safety;
2. Works under a range of temperature conditions;
3. Cooling triggered on opening;
4. Cooling takes less than 10 seconds;
5. No toxic residue;
6. Can is able to be recycled;
7. On false trigger;
8. Sensible shelf life. [20%]

(b) The key here is to acknowledge that the fault tree should address the whole user experience. Logic gates are most likely to be OR gates.



[30%]

(c) This 'fault tree', the inverse logic of the tree above, leads to a successful outcome. It is likely to be linked to the previous tree where an acceptable customer experience, will contribute to commercial success. Logic gates are most likely to be AND gates.



[20%]

(d) FTA is particularly good when 'mapping' and 'testing' causal links to a top event, which may be positive or negative. FMEA is particularly good at evaluating a process, system or product response to failure, by 'testing' the impact of system component failures. In practice, both methods are often used to investigate a system. FMEA is often used to identify potential risks which can be investigated further using both FTA and FMEA. [30%]

3 (a) The potential benefits of QFD can be briefly summarised as follows:

- Encourages cross-functional teamwork throughout the product development process, encouraging communication and cooperation
- provides a mechanism for increasing the use of marketing inputs
- Focuses the development team's minds on what they don't know
- Focuses on customer needs, not product features
- Prevents wild unqualified assumptions
- Ensures that a wide range of issues are considered, including customer requirements, technical characteristics and competitive products.

The potential drawbacks of QFD can be briefly summarised as follows:

- Requires a cross functional team, including, for example, representatives from marketing, engineering and manufacturing
- Can be exceedingly complex, time consuming and tedious
- Can be too analytical - a numerical answer can be treated as a 'right' answer
- Requires some training and strong facilitation initially
- There are many variants of QFD, each with their own terminology
- There is the risk that attention is devoted not to serving the customer, but to serving the matrices.

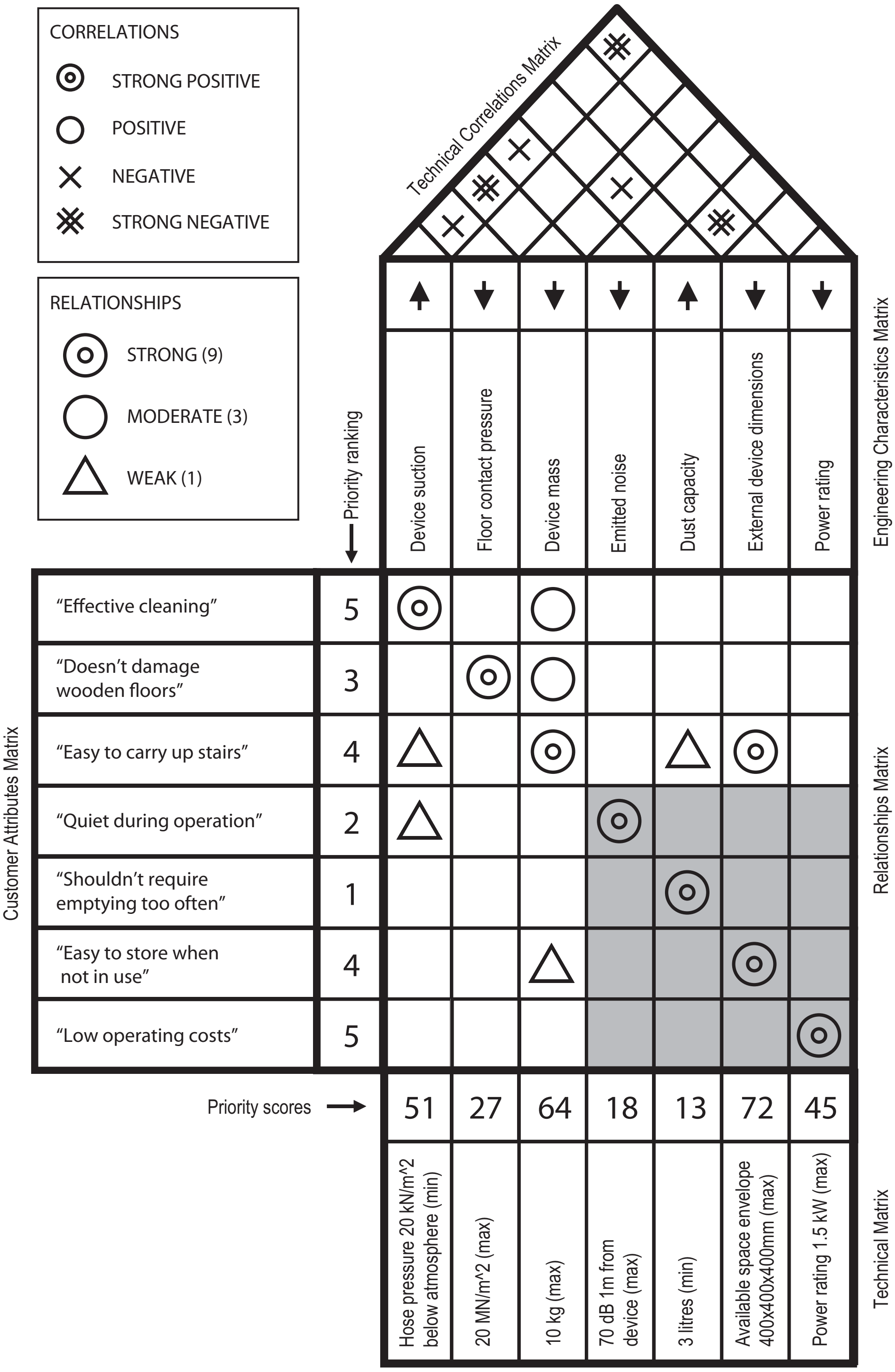
Full marks are available for five distinct points across both parts of the answer.

(b, c) An example of a completed QFD chart is shown overleaf.

(d) The QFD chart suggests that "external device dimensions" is the most important engineering characteristic. This is a consequence of two "strong relationship" marks in the relationships matrix, each associated with high priority rankings. The customer requirement to carry and store the device are not independent of each other and this contributes to the high score.

(e) Various answers are possible, but it is plausible that the following correlations are strongly negative: (i) increasing suction and decreasing mass (due to motor size); (ii) increasing capacity and decreasing external dimensions (due to housing the dust); and (iii) increasing suction and decreasing operating costs (due to motor power). All of these are likely to be important because they involve at least one high scoring engineering characteristic.

(f) Marks are available for identifying a contradiction and suggesting ways of resolving it. For example, using answer (ii) in (e) above, the contradiction between something being both big and small must be resolved. This could involve designing the dust container to occupy voids left by other components; making the dust container collapsible and external to the device; compacting the dust prior to storage, using external dust storage that is not part of the device (e.g. plumbed into the house), etc. The use of creative methods such as the SCAMMPERR list is useful here.


CORRELATIONS
STRONG POSITIVE
POSITIVE
NEGATIVE
STRONG NEGATIVE
RELATIONSHIPS
STRONG (9)
MODERATE (3)
WEAK (1)
Technical Correlations Matrix
Priority ranking
Device suction
Floor contact pressure
Device mass
Emitted noise
Dust capacity
External device dimensions
Power rating
Engineering Characteristics Matrix
Customer Attributes Matrix
"Effective cleaning"
5
"Doesn't damage wooden floors"
3
"Easy to carry up stairs"
4
"Quiet during operation"
2
"Shouldn't require emptying too often"
1
"Easy to store when not in use"
4
"Low operating costs"
5
Relationships Matrix
Priority scores
51
27
64
18
13
72
45
Hose pressure 20 kN/m^2 below atmosphere (min)
20 MN/m^2 (max)
10 kg (max)
70 dB 1m from device (max)
3 litres (min)
Available space envelope 400x400x400mm (max)
Power rating 1.5 kW (max)
Technical Matrix

4 (a) For example,

D/W	Wt	REQUIREMENTS
		GEOMETRY
D		• Fit into hiking backpack (<10x10x50 cm)
W	H	• Be lightweight (<4 kg)
		MATERIAL
D		• All materials to be waterproof
D		• All materials to be resistant to low temperatures (-40ºC)
		SAFETY
W	M	• No finger traps during use (no gaps > 2 mm)
D		• Conform to international safety standards for consumer electrical products
D		• Prevent the turbine becoming dangerously overspeed in high winds
		ERGONOMICS
W	L	• Should be easy to locate in the dark
W	M	• Should be easy to set up in the dark
W	H	• Should be capable of set up and tear down whilst wearing gloves.
		ENVIRONMENTAL IMPACT
W	H	• Should not negatively impact the local or global environment during use, production and at end of life.
		OPERATION
D		• Should produce > 25W electricity before reaching overspeed
W	H	• Should permit connection to a wide range of current and future devices
W	M	• Turbine should extract maximum available energy from the wind (but see 'overspeed' above)
		MAINTENANCE
W	M	• Should require minimum maintenance
W	M	• Should be maintainable with minimum of specialist tools
		COSTS
W	H	• Unit cost less than £500

Any sensible collection of requirements could gain full marks, but the requirements list should discriminate between demands and wishes, wishes should be weighted, the requirements should be quantified wherever possible and should be structured under several high-level headings.

(b) The overall function is to convert wind energy into electrical energy. Sub-functions might include:

1. convert (linear) air energy into (rotational) shaft energy
2. convert (rotational) shaft energy into electrical energy
3. direct turbine into the wind (if needed)
4. permit shaft to rotate relative to generator
5. secure turbine relative to air velocity
6. prevent turbine becoming overspeed.

(c) For example, using the numbered sub-functions above:

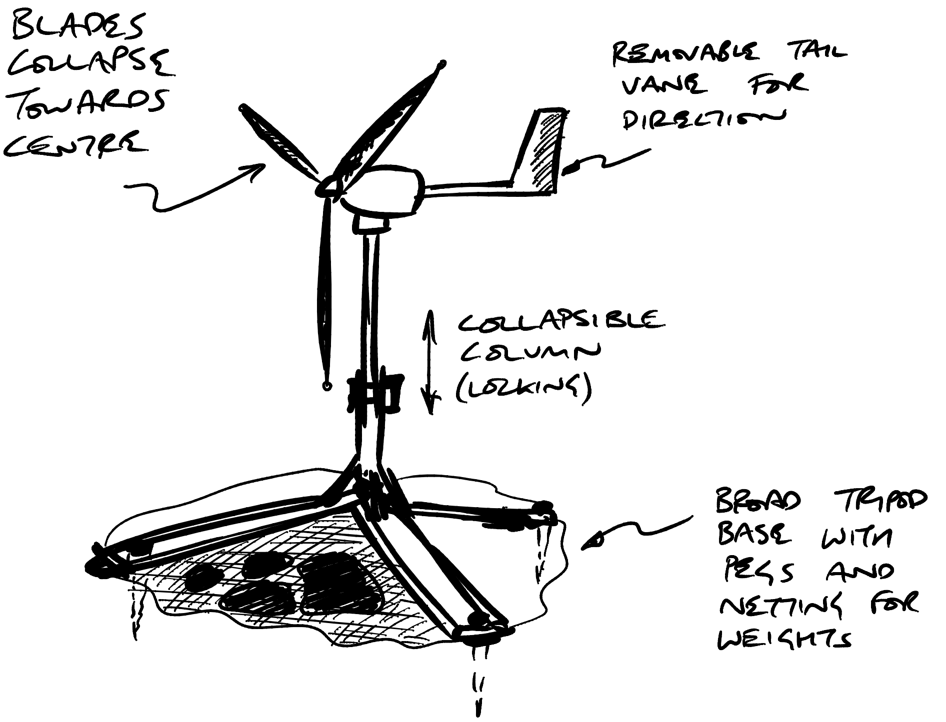
SUB-FUNCTIONS	**SOLUTION PRINCIPLES**		
1	Horizontal-axis turbine (blades)	Vertical-axis turbine (large sails)	Vertical-axis turbine (thin blades)
5	Drive spike into ground and tether with tension lines	Use a tripod weighted with nets filled with ice or rocks	
6	Use mechanical governor: increased speed increases drag	Use electronic system: sense wind direction and steer turbine out of wind	

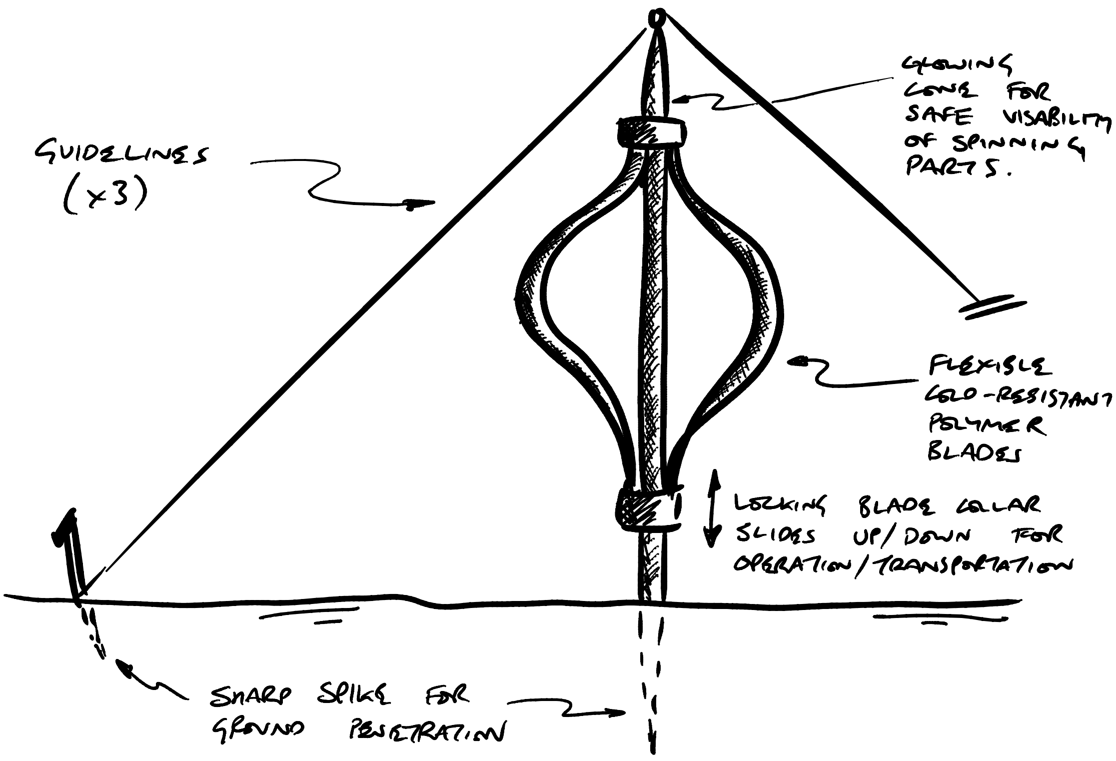
…

(d) Various designs are possible, each at different levels of detail. Designs should attend to the issues specified in the requirements list. Issues of transport, installation and operation are likely to be especially important.

In designs, the use of high-visibility, high-contrast, colour-coded materials is advisable. Attention should be given to the visibility of high speed components that might pose a threat to users. Attention to maintaining directionality in variable wind is important, as is avoiding the risk of overspeed. Discussion of braking systems, blade feathering, variable drag is expected. The designs should be evidently transportable, either through the use of collapsible or removable components or by some other means.

The basic geometric arrangement of a pair of possible designs is sketched overleaf to demonstrate some vertical- and horizontal- axis options.


BLADES COLLAPSE TOWARDS CENTRE
REMOVABLE TAIL VANE FOR DIRECTION
COLLAPSIBLE COLUMN (LOCKING)
BROAD TRIPOD BASE WITH PEGS AND NETTING FOR WEIGHTS


GUIDELINES (x3)
GLOWING CONE FOR SAFE VISABILITY OF SPINNING PARTS.
FLEXIBLE COLD-RESISTANT POLYMER BLADES
LOCKING BLADE COLLAR SLIDES UP/DOWN FOR OPERATION/TRANSPORTATION
SHARP SPIKE FOR GROUND PENETRATION