# Catalyst

## Journal of the Amateur Yacht Research Society

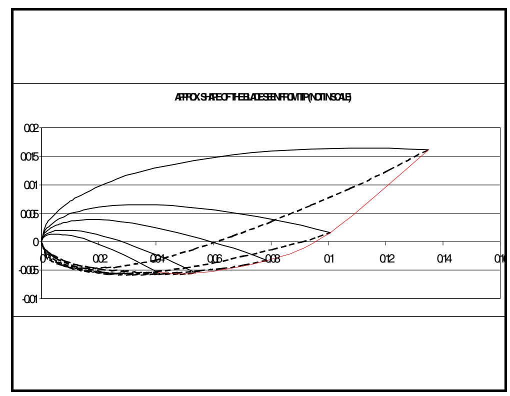
Number 11 January 2003

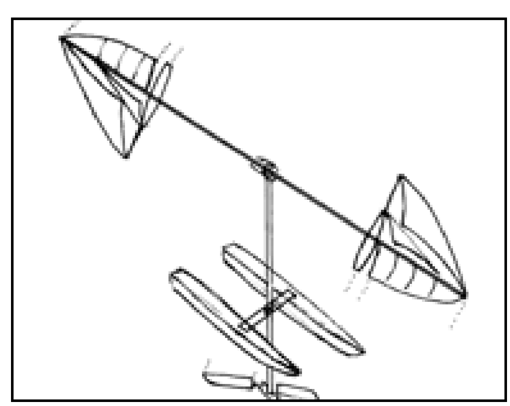
## Features



## Regulars







*Michael Wingeatt's "buoyant keel" monohull tacking on Lake Windemere, UK. Note the absence of wake. Photo: Wingeatt*

# Catalyst

Journal of the
Amateur Yacht Research Society



*Catalyst* is a quarterly journal of yacht research, design, and technology published by the Amateur Yacht Research Society, BCM AYRS, London WC1N 3XX, UK. Opinions expressed are the author's, and not those of AYRS. AYRS also publishes related booklets.

Contributions are welcome from all. Email them to **Catalyst@fishwick.demon.co.uk**, or send (at your risk) disks or typed copy with illustrations to the Society's office. AYRS can take no responsibility for loss or damage.

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# John Hogg Prizes 2003

January is the time of the announcement of the results of the John Hogg prize for innovation. This year the prize has been shared between two entrants – Mario Rosato or his theoretical work on windmills, and Mike Wingeatt for his buoyant keel sailing monohull design. Congratulations to both of these, and to the runner-up, Giles Whittaker for his hapa stabilised sailing craft. The full Judges report will be found on page 3.

As an outside observer (since I am not a member of the Judges Committee), it struck me that some of the entries had significant merit, but were let down by poor presentation of their case. People really should not expect the Judges to wade through a disconnected set of jottings to find the gems within. In this competition as in so many other things, the ability to get the ideas across is proving as important as the ideas themselves. All of the short listed entrants paid attention to this, in one case including a video; as did a number of the other entries. As an engineer who finds it easier to build things than to write fluently, I can appreciate the difficulty; but as an Editor I can also see the importance of communication.

The two winning entries are included in this edition of *Catalyst*. Others will be published in future. (Articles on Robert Frazer's and Ian Smith's entries have already been published). In some cases, the submissions are too long for this magazine, and there will be space only for extracts.

Entries for next year's John Hogg Prize should be submitted by October 2003.

# AYRS - John Hogg Memorial Prize 2002 - Report of the Judges

In this, the second year of the competition, nine entries were considered. One had been held over from 2001 when it arrived late, and of the other eight, seven were by newly entering researchers; compared with six entries last year.

We have decided to divide the prize equally between Mario Rosato and Michael Wingeatt, both of whose entries are original and show great promise for future development. The other short-listed entrant, Giles Whittaker, receives a year's free AYRS membership: all three will have received their prizes and certificates at the 2003 London Boat Show.

The entries cover almost the complete range of existing sailing craft, and one entry of a more philosophical nature postulates some hundreds more! So the judges have not had an easy time, and have had to widen the scope of their knowledge considerably. Readers of *Catalyst* will be able to join us in this as the entries are reported in print.

Most of the entries were well presented, and for the first time one included a computer floppy disc with a program. One comprised prints from a web site, which resulted in too many pages, and captions for photos on the preceding page, doing nothing for the judges' patience. Another last-minute entry sent by e-mail also did not do itself justice due to poor reproduction and again caption displacement. For next year, only hard copy will be acceptable for the competition (but the Editor of *Catalyst* would no doubt appreciate a soft-copy for publication).

The three entries short listed, and in alphabetical order, are:-

Mario Rosato (Barcelona). A disc with an Excel 2000 file, and nine pages of very clear instructions, enable anyone (with Excel 2000 and the skill to drive it) swiftly to design a wind turbine to meet their own requirements. These can range from boat propulsion to electricity generation via any hybrid in between. This entry parallels to some extent the work of Jim Wilkinson in designing his REVOLUTION wind-turbine powered catamaran (www.multihull centre.co.uk, and MULTIHULL INTERNATIONAL No 403, September 2001). Jim's paper awaits publication in the Editor's in-tray, the two will make a good AYRS Publication. The main technical comment is that the interference factor (a) cannot be controlled: for afloat propulsion a value of 0.1 is desirable so that the drag of the turbine rotor is minimised.

Giles Whittaker (Scotland). He seems to have solved the long-standing problem of getting a hapa to run satisfactorily. It may offend purists by being attached mechanically to the craft, mono- or multi-hull, displacement or foil-borne, but the video shows dramatically how well it holds a variety of model craft almost bolt upright in seas that would seriously challenge any other craft, and still allowing excellent speeds and control on all points of sailing. Naturally vulnerability is in question. The test in due course must be at full size.

Michael Wingeatt (England). After years spent thinking about how to design a cruising boat that would be safe, comfortable, fast and cheap, 'the answer came in a blinding flash'. Simplicity itself, his design puts all the displacement in a deep ballasted keel, with the substantially flat-bottomed hull acting as an end-plate at the water-line. Tank trials at the University of Central Lancashire confirmed that this suppresses the waves normally made by displacement hulls.

He has now built a 29ft (8.788m) long full-size prototype, launched in February 2001. Displacement is 2605lb (1184Kg), sail area 22 sq.m. With four crew on the Solent in June 2002, wind Force 3 - 4, GPS indicated regular speeds of 9 knots to windward, 12 knots off the wind, and a peak of 18.3. Remembering that 1.4 time the square root of 29 is 7.5 knots, this is impressive for a first prototype of this new design. We think the 18.3 should be taken with a large pinch of salt; GPS does have glitches, as do most speed meters 'touching a peak'.

The other six, also in alphabetical order, were:-

Gabriel Elkaim (USA). His entry was his thesis for a PhD at Stanford University, California. The judges have concluded that his work goes beyond the definition of amateur and therefore could not qualify as an entrant.

The thesis is an impressive report of a project to design, build and test an autonomous GPS controlled wing-sailed catamaran, as a prototype vehicle for unmanned voyaging, for example as a weather reporter. In one test the craft was able to track a given line to within 0.3 metres under sail, rather better than most helmsmen!

Probably of more interest to sailors is the design of the wingsail (using XFOIL), which appears to improve upon John Walker's designs for BLUE NOVA and ZEPHYR.

Robert Fraser (Canada). His entry, 'Ergonomically-Correct Oars, Pulling without Stess' arrived too late for 2001, so was considered this year. The project was reported in CATALYST No 9, July 2002.

Ambras Janko (England) submitted a novel design of paddle wheel that holds the paddles vertical as they rotate, to improve their entry and exit to and from the water, without the complicated linkages seen previously.

Roberto Rampinelli (Italy) has designed a proa that tacks rather than shunts; this is a monohull with two wingsails pivoted about two axes at deck level. The windward one is hoisted close-up to the mast, which acts as a slat; the leeward one lies horizontally, giving some aerodynamic lift. Both have at their tip a small float, which has an inclined surface-piercing foil to provide more righting moment. A student project at the University of Milan showed that performance exceeds that of a catamaran of similar weight and geometrical details. A sailing model test is dismissed because the wind gradient within a few centimetres of the surface does not replicate full size; so we await a full-size prototype!

Peter A. Sharp (USA). Starting, as he did last year (CATALYST No 3, January 2001, page 26) with Bauer's 'Downwind Faster Than The Wind' windmill bicycle, he examines through analogies the potential possibilities of defining a large number of so-far undreamed-of types of sailing craft.

A recent reference to downwind windmill craft, with a full and rigorous mathematical treatment and polar performance diagrams is given in Joe Norwood's '21st Century Multihulls', AYRS 120, page 49 et seq, January 1996. Make sure you have the Errata to AYRS 120, a 12 page leaflet, 1999.

Ian E. Smith (Australia). His entry is described in CATALYST No 10, October 2002, page 24. He has devised a trailer-launched catamaran with an ingenious procedure for floating the craft off the trailer. The concept may owe something to Ian Farrier's method of folding floats under a multihull. His design meets his requirements and can enable people to get afloat safely, enjoyably and with home build, cheaply.

The next award will be made at the London Boat Show 2004. The closing date for entries will be 15 October 2003.

# AYRS John Hogg Memorial Prize - Revised Rules for 2003.

The AYRS announces the third award of a Prize in memory of John Hogg, the distinguished amateur yachting researcher, who died on July 24th 2000.

The prize of £1000 has been donated by his family to commemorate John's life and work.

The aim of this international award is to encourage and recognise important amateur contributions to the understanding and development of sailing performance, safety and endurance. Preference will be given to current work where the prize money is likely to benefit further development.

Nominations, whether of oneself or another, should be submitted to the Amateur Yacht Research Society, BCM AYRS, London WC1N 3XX, UK, to arrive by 15th October 2003. Nominations may be made by or for anyone, whether or not a member of AYRS. Those nominating another must obtain the written agreement of the nominee and forward it with the entry.

Submissions must be made in English, in hard copy sent by post, to arrive by the due date. FOUR COPIES are required– one for each of the three judges and Secretary. Electronic transmission, the use of web site pages and direct extracts from patent applications (which are written by and for lawyers and can generally be shortened) have resulted in unsatisfactory presentation, hence the need for hard copy of a dedicated paper conforming to the details given below. The vagaries of reproduction from disks are such that hard copy for the entries is essential.

'Amateur' in this context means work done as a pastime and largely self-funded. Details should be given of any grants or other funding or assistance received. Work carried out as part of normal employment is not eligible, but subsequent commercial exploitation of research need not debar work carried out originally as a pastime. Those with ongoing projects are as eligible to apply as those whose work is completed.

The submission should cover the following:-

• A summary, of not more than one page, identifying the nominee and the work submitted, and including a short statement of its merits to justify its submission.

• The description of the work itself, its novelty, its practicality, its degree of success to date, and (briefly) hopes for the future. The work will be judged on the final result achieved to date. Please spare us a complete history of your researches except to the extent that they are truly relevant. The use of your already published material, whether or not peer reviewed, incorporated in an entry, is welcome. Diagrams, graphs and photographs may be used, video material on VHS PAL system can be helpful. Programs on disk may be entered as part of a submission (accompanied by explanatory text etc). Appendices may be used, e.g. for mathematical workings. Direct reproduction of pages from an author's web site has generally proved unacceptable (due for example to captions appearing on the page preceding the image) and is not welcome.

Entries should be printed on A4/letter paper in a legible font. Successful short-listed entries to date have ranged from a maximum of 22 sides with 6 of photos, to one winner with 5 sides, 3 of photos and one A3 drawing. Clarity, legibility and brevity pays!

• Separately, a brief biography of the nominee(s) may be included, and their amateur status and qualifications should be explained.

• Nominees may care to say how they will use the prize should they win.

• AYRS will wish to publish brief summary accounts of entries, and may also seek further articles from entrants. To this end it will be helpful if entries can (if necessary) readily be abridged for publication in *Catalyst*. Grant of permission to publish such articles is a condition of entry. However any information received as part of a submission will be treated 'In Confidence' if so marked.

The winner and runners-up will be announced at the London Boat Show in January 2004. All short-listed entrants will receive one year's free membership of AYRS and a certificate.

The Judges, whose decision shall be final, will co-opt experts as required. Submission of an entry will be taken as signifying the entrant's acceptance of these rules.

Requests for copies of the definitive set of rules, and queries concerning possible entries may be made by phone or e-mail to the AYRS Honorary Secretary on tel/fax +44 (1727) 862 268; e-mail ayrs@fishwick.demon.co.uk.

## Speed Sailing

About this time of year we are all looking forward to the long summer months when the cold bleak days (like today) are forgotten and next winter is so far into the future that it is not worth thinking about.

Naturally next years activities need some preparation or the weeks would slip by without much action.

So from the Weymouth Speed Week crew, here are a couple of dates you may like to put in your 2003 calender.

From Monday the 12th of May to Friday the 16th of May we will be going to have a testing session of our equipment and we will be based at the Castle Cove Sailing Club on Old Castle Road.

This week is not intended to be a formal event but a get together on the beach to test out whatever comes to hand. We of course will be taking the timing equipment with us and a couple of people will be bringing their boats.

If this appeals to you then give Bob Downhill a ring on 01323644879 or Norman Phillips on 01737212912 as we need to have some idea of numbers. There will be some cost to put this on but it should not be excessive.

Weymouth Speed Week 2003 has been booked at the Weymouth and Portland Sailing Academy and this event runs from Saturday 4th of October to Friday the 10th. All the costs and arrangements are similar to 2002.

We sincerely hope that there will be more wind so we do not have a repeat of the balmy breezes of Weymouth Speed Week 2002.

➔

The contact telephone numbers are the same or of course you can e-mail Nick Povey on nick@speed sailing.com or leave a message at www.speedsailing.com.

The Speed Week team look forward to seeing you in Portland in 2003.

## Opps still alive

I have been rather busy since moving to Spain. I REALLY did mean to contact you, get the Catalyst sent here - its the old intent thing. Anyway I hope you can forgive and please advise how I can send my contribution from here? I'm still working on Opps (see *Catalyst* April/May 2001 Fred Ball's workshop) had three 5 meter models semi-operational - sufficient to have the local yacht club murmuring "witchcraft" and the like.

It rather looks that opps - can do and I'm making a smaller model (one meter) to test against the waves/in my swimming pool (I'm less than an hour from Tarifa). The final unit is to be totally electric/battery (wind/water gens + solar panel feed batteries) plus sails of course. And the I anticipate the propeller to be unidirectional (between twin hulls); would appreciate missed Catalysts (latest received January 2002), especially anything from Theo Schmidt on "Electric Propulsion Design"; in fact any help I can get!?

*Cheers Mike Berry*
*mikeberry@wanadoo.es*

PS Please also realise this is a wonderful test area

## Blakeney Harbour, Blakeney Freshes scheme, Salthouse Sea Defence scheme.

The UK Environment Agency is tackling two crises which are largely man made. A third exists which has similar weight, which is the accelerating and relentless destruction of Blakeney harbour, very much a man made crisis.

The Agency has announced a Consultation Period to study the re-routing of the River Glaven. The Glaven has a present course which is likely to be badly affected by a shoreward movement of the beach. The Glaven route will suddenly disappear. This will cause rapid siltation and have a devastating effect on navigation throughout Blakeney Harbour and its feeder channels.

There is an advanced plan to protect Salthouse and the Coast Road. Consideration is being given to re-routing the Glaven through Blakeney Freshes.

We have made a submission to the Enironment Agency intended to bring the plight of Blakeney Harbour into focus, identify the potential that the two schemes under consideration have to address this problem, To suggest a method which could provide an extremely low cost solution.

This may be of interest to you.

Further details can be obtained from me,

*Morris Arthur*
*tel. +44 (1263) 740156*

# A Search for Effectiveness

## (Efficiency would help!)

Dear Catalyst

The limit of force that can be provided by a sail on a boat is the overturning moment capsizing the boat. This can be mitigated by weight of hull plus ballast offset from buoyancy centre or dynamic forces from foils, or by inclined rigs [captive kites]. Reducing the height of centre of effort of the rig would also help.

The efficiency of a sail involves the skin friction and induced drags. The latter is caused by the change of momentum in the passing air ('down-wash' in aeroplane terms) by the force on the sail. As in jet propulsion by propellers, oars or suchlike, the momentum change involves (velocity change) × (mass of fluid moved), the energy required or taken out by drag forces involves (the same mass) × $(\text{velocity})^2$.

Tall, thin chord, high aspect ratio sails plus glider wings as examples make a small downwash velocity change to a wide strip of air very efficient. Large mass is proportional to a × b × air velocity. (See Figure 1). The disadvantage in boat terms is that the centre of this activity is at height C (Figure 1) involving large overturning moment when side force is resisted by a keel low down.

A short-masted wide rig would avoid the problem of large height C, and could still provide large cross-section of affected air stream. The proposed use of this unproven [and to me incalculable] hypothesis is an extreme form of lateen rig comparable to the airmans paper dart style [Regallo?].

In this case the downwash affected cross-section is a horizontal slab, less than Figure 1 but not bad! These sails operate at steeper incidence than narrow wings.

Add to the low height wide rig a degree of 'top to windward' inclination in kite style, and for sailing close to the apparent wind, the yard of the lateen sail becomes an inclined mast, permanently fixed on the centre line of the 'yacht'. This can be supported by split wishbone struts spread at the base to enclose the sail on one or other tack, the sail being sheeted to alternative booms, loose footed. These two booms, spread at twice the angle of sheeting of the sail become the structure of the 'yacht'. The mast , two struts, two booms and a thwart between the booms at struts' base form a rigid structure of simplicity – no adjustment needed to sail close-hauled. The fineness of the chosen sheeted angle of the sail dictates the angle between the booms – the plan of boom-thwart structure (Figure 3).

To test this rig, 3 point support on wheels relates to the rig structure nicely. Two at thwart ends, single steering bow wheel.

As at December 2002, this experiment is in hand with a model approximately one-fifth scale of a 10 $m^2$ sail version. For the model an arbitrary 7½° mid line of sail sheeted angle gives a boom angle 15°to centre, 30° between booms. The thwart-strut triangle was made equilateral, so mast slope is 25° approximately. The line of pull of the sail should pass through the windward strut-thwart joint. As the model wheels are below this, overturning in strong winds is predictable unless ballast [crew equivalent] is added to bring the effective centre of gravity over the upwind wheel.

If this will go and be controllable and fast with radio steering and sheet change for tack only there will be hope.

Technical help over radio gear would be appreciated.

### Given some success with lateen rigid rig sail on wheels, search for effective hull.

The joint between boat and water is most reliable when compressive – pull down by foil or hapa is always subject to sudden loss if water depth is reduced by waves and will not re-instate once lost. Three touch points are required – two with continuous servo adjustment by crew is too energetic for my age group. Steering by crew-controlled balance act on one point lateral resistance is also too much. Two lateral resistances as keel and rudder are okay.

Hence my choice:- Two main load supporting hulls for static or low speed lateral stability – to become dynamic lift at higher speeds. One control hull and rudder unit – also to become dynamic lift at speed. If to be compressive at all times and suit the previous rig structure this is a bow rudder and canard lift foil as a combination, which could be achieved by a “V” of two foils which can each change incidence about their axis; together for lift variation or in opposition to steer.

The experiment required but not yet begun is to tow the model equivalent and prove inherent stability and direction control and any drag hump involved in transition from hydrostatic rest to low speed and lift off into hydrodynamic support at low drag.

**Stage 3. Go for real with some degree of confidence. [Sponsors welcome!]**

## Notes on Control Stability

**The rig**

If the force resisting the lateral pressure in the sail is upwind at a point analogous to the pilot’s weight of a hang-glider, the sail will tend to correct itself in directional balance. It is preferable to have a centre-board equivalent upwind of the sail, a problem with multi-hulls that lift out.

**The Hull**

Inherent longitudinal stability is there in longboats and easy with longitude separated multi-hulls. Pressure for bows down increases with sail drive force.

The proposed bow rudder canard lift foil system is that the bow “V” will level according to load by the inherent change of area with immersion, far enough from the weight-carrying to be small forces so a small depth change.

The main foils will change angle, and perhaps area too as surface piercing is intended, to be led by the nose of the bow foil. As they lift, the angle reduces.

Using the windward of the main support foils as the lateral resistance main point is what the sail requires, but may become a problem with inertial forces in sudden changes of steering direction. Unsolved detail, but similar to Chinery/Holtom foiler difficulties. Transmit protection from disaster by the partial use of the start up buoyancy ‘in extremis’ may be enough.

If the simple actions available to radio control are enough to sail a model the real size will be worth building.

*O. T. (Sue) Lewis*
*17 Andover Road, Upavon, Pewsey, Wiltshire, SN9 6AB;*

## Appendix

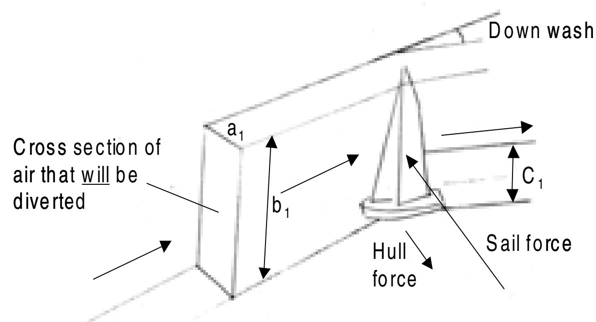


*Figure 1: Tall rigs*

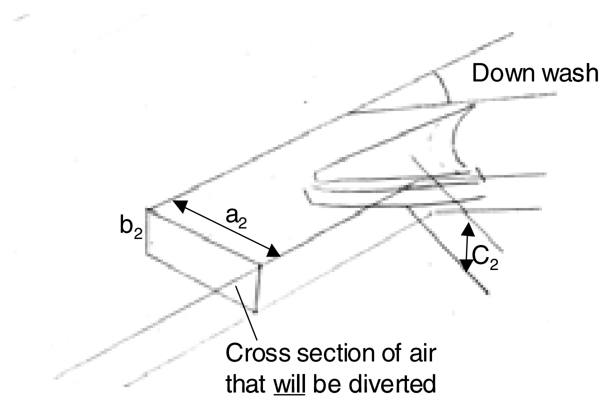


*Figure 2: Long low rig at larger angle to wind*

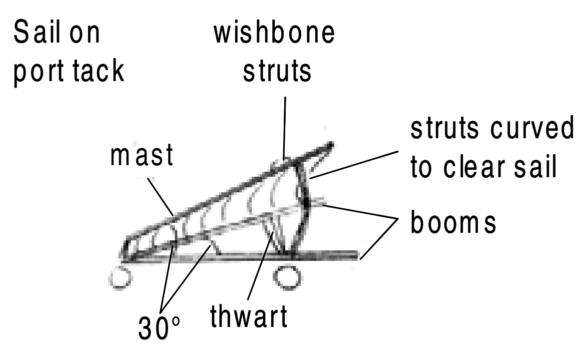


*Figure 3: Structure of rigid rig*

# A Displacement Hull and Keel Design Unrestricted by the Square Root of Waterline Length Rule

Michael Wingeatt

I have designed a hull and keel arrangement for displacement vessels that does not produce bow and stern waves and therefore the maximum speed is not limited by the square root of the waterline length rule. The hull and keel design of this concept whilst very simple in execution breaks a fundamental rule of physics limiting the performance of displacement vessels. This has been done in two ways.

1. The rule of physics limiting the speed of displacement vessels to 1.4 times the square root of the waterline length only applies to vessels with a beam to length ratio of less than 1:5. I have therefore designed the part of the vessel that passes through the water with a beam to length ratio, in this case, of 1:9. This has been done by means of a long narrow hollow keel the volume of which displaces the exact weight of the boat including all rig, equipment and ballast.

2. The result of this is that the hull rests at surface level. The design of the hull is such that it has a flat bottom extending either side and fore and aft of the keel. This prevents any propensity for the keel to create bow and stern waves as it effectively separates the gas and liquid (air and water) at surface/waterline level keeping the changes in pressure, referred to in the detailed description, entirely within the liquid (water).

I have had a 1:10 scale model tested in a fluid dynamics tank at the University of Central Lancashire and have subsequently built an 8788mm long prototype with a displacement of 1184kg and a sail area of 22m$^2$. This boat has been recorded at a speed of 18.3 knots in the Solent in June 2002 with a crew of four.

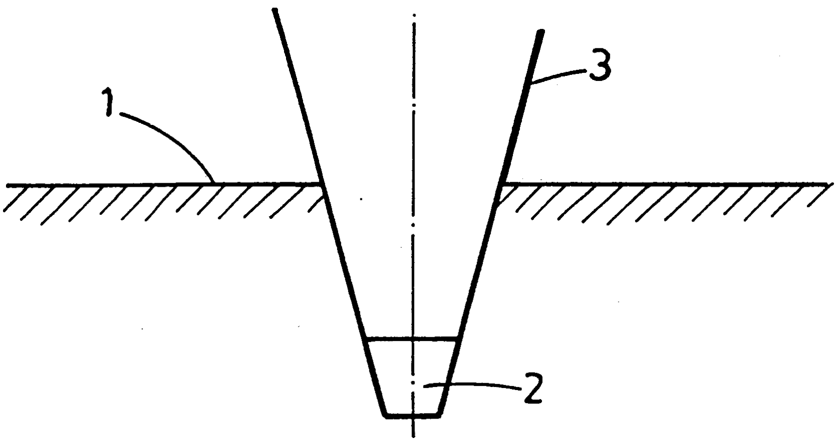


*FIGURE 1 -- a section through the keel*

## DETAILED DESCRIPTION

I read with interest the recent Notes from Toad Hill (Catalyst No. 9 July 2002) concerning the AYRS Publication No. 1 distributed in 1955. In particular I was concerned that of the original objectives of the Society only No. 3 "To produce a safe, comfortable, fast and cheap cruising boat." had not been achieved. I believe the four parameters have not been successfully combined in one boat because the first two have traditionally been at odds with the last two. To be cheap a boat needs to be relatively small. To be fast a small boat needs to be light to be able to plane. However to be comfortable a boat needs at least rudimentary accommodation which adds weight and to be safe a boat has to be self-righting which means further weight in the form of ballast.

The additional weight of providing comfort and safety in a cheap (small) boat prevents that boat being fast as it cannot plane. If a boat cannot plane it becomes a displacement boat. The 1.4 x square root of waterline length rule limits the maximum speed of displacement boats. Therefore the maximum speed of cheap (small) boats, which are safe and comfortable, is between 5.6 and 7 knots (waterline lengths 16'-25'). It is this fundamental rule that has ensured that AYRS original objective No 3 has never been achieved. It is also the reason why the number of small cruisers constructed has declined as noted in 'Deceased One Designs' (also in Notes from Toad Hill, Catalyst July 2002). The factor X referred to in that article is, I believe, the paradoxical parameters of objective No 3.

Speed is required in a cruiser not only to race, which is human nature, but to reduce passage times or increase cruising range. When trying to reach a destination, in a cheap (small) boat, speed also becomes a safety factor when outrunning the onset of bad weather or nightfall and access is reliant on tides. Even when under power the waterline length rule applies. Increases in standards of living and expectations generally have the knock on effect that people in the market for cruising boats are expecting more comfort in their boats which creates even more weight exacerbating the problem further. The only way to encompass all the seemingly paradoxical parameters of objective No 3 is to find a way to break the waterline length rule.

Traditionally designers have emulated nature in providing fish like solutions for the shapes of hulls. The fundamental difference between a fish and a boat is that one is normally fully submerged and the other only partially submerged. As a boat passes through both liquid (water) and gas (air) it creates areas of differing pressure within both. It is the interaction of the liquid (water) and gas (air) at the water's surface that allows the formation of waves. The formation of a bow

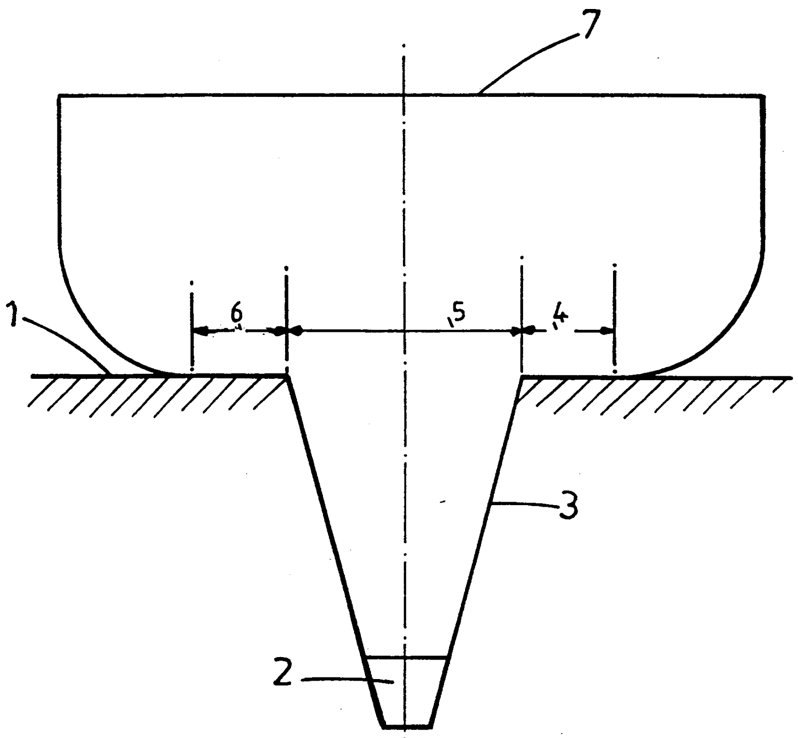


*FIGURE 2 shows a section through the hull and keel*

wave occurs because the increased pressure in the water, the movement of the hull creates forces the water upward into the air at lower pressure. The trough is formed as the water pressure decreases as it rushes around and under the hull forcing the air downward into the water at lower pressure. The stern wave is formed as the water rushing from around and under the hull increases the water pressure behind the hull again forcing the water upward into the air at lower pressure. I have designed a hull and keel configuration that does not create the bow and stern waves that limit maximum hull speed under the waterline length rule.

In November 1999 1 applied for patent protection on the hull and keel design. I reproduce that application, in part, below:

"This invention relates to a hull and keel design for boats of the type that displace the water they pass through rather than skim or plane across the surface.

Traditionally boats have relied upon ballast inside the boat or a heavy external keel, combined with the breadth of the hull, to resist overturning forces and provide a self-righting capability. The added weight means that, to move, the hull of the boat must displace the water, upon which it floats, around the hull. This displacement of water creates a bow wave at the front of the boat, a stern wave at the back of the boat and a trough between the two waves. The interaction of these two waves restricts the maximum speed of the boat through the water since as the speed of the hull increases the size of the bow and stern waves also increases and the boat settles deeper into the trough created and cannot escape. As a general rule the maximum speed, in knots, of a displacement hull, of this type, is a coefficient of the square root of its waterline length in feet.

There have, to date, been two methods of overcoming this restriction on hull speed. The first method is to design long narrow hulls since the general rule does not apply to hulls that have a waterline length exceeding five times the waterline breadth as these narrow hulls cut through the water without creating bow and stern waves that can interact. However individually these narrow hulls do not provide much resistance to overturning forces so two or three hulls are use together and generally do not use ballast (catamarans and trimarans). The disadvantages of this arrangement are excessive width and lack of ability to return to the upright position following capsize. The second method is by designing hulls with flat

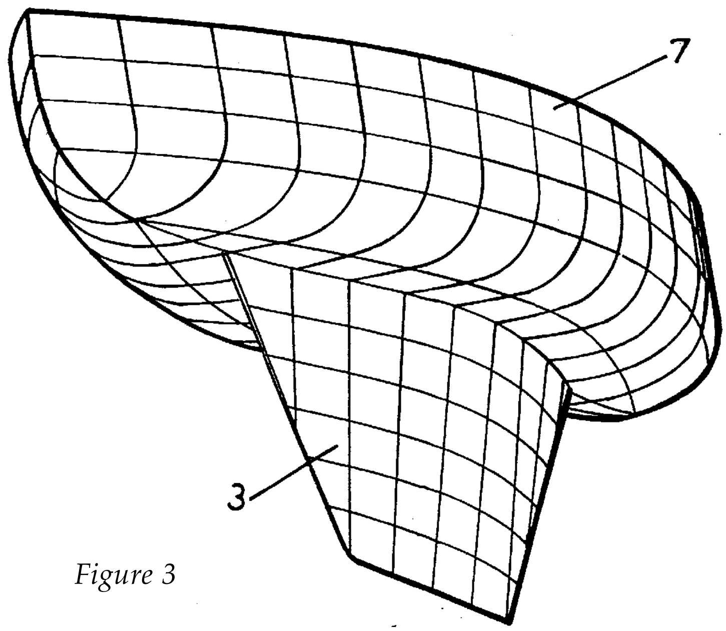


*Figure 3*

Another essential feature is that the length of the keel exceeds five times the width of the to prevent the creation bow and stern waves that can interact to restrict maximum speed A third essential feature is that where the hull and the keel meet, the hull, either side of the keel, should be as near a horizontal flat plane as possible on or near the surface of the water. The effect of this is to flatten any waves the keel may create and allow the hull to provide immediate resistance to overturning forces.

surfaces and with no fixed ballast, boats can cease to be displacement types by having the ability to climb out of the trough onto the bow wave and skim or plane across the surface of the water. The disadvantages of this arrangement are that size is restricted by the reliance on no fixed ballast with lightweight construction and again lack of ability to return to the upright position following capsize.

An object of this invention is to provide a hull and keel design that solves the problem of fixed ballast displacement boats creating bow and stern waves that interact to restrict the maximum speed of the hull through the water as described above. This invention does this without excessive width, with no restriction on size, and with the ability to return to the upright position following capsize.

An essential feature of this invention is a keel with enough buoyancy to support any ballast and enough additional buoyancy to support tile weight of the hull to which it is attached so that the hull rests on or near the surface of the water rather than in it.

Preferably the hull and keel should be made of the lightest boat building materials available such as plastics reinforced with carbon or glass fibres or wood or steel or a combination of these or other materials.

A preferred embodiment of the invention will now be described with reference to the accompanying drawing in which:

As shown in figure 1 the keel 3 is hollow in section with enough buoyancy to support its own weight and that of the fixed ballast 2 so that it floats well above the surface of the water I.

As shown in figure 2 the keel also has enough additional buoyancy to support the weight of the hull 7 to which it is attached so that the hull 7 rests on or near the surface of the water I rather than in it. The length of the keel 3 must always be greater than five times the width of the keel shown at S. Where the keel 3 meets the hull 7 there should be flat surfaces, shown at 4 and 6, on or near the surface of the water I. These will flatten any wave formed by the keel 3 as it moves through the water and gives tile hull 7

*Photo 4*

a shape that will provide immediate resistance to any over turning forces.

This example of the invention is given for description purposes. The hull 7 and keel 3 can be of any size. The width of the hull 7 in relation to the keel 3 can vary and the shapes of the hull 7 and keel 3 can vary."

## THE STORY SO FAR

The construction of the hull comprises 44mm x 19mm iroko strip planking on 32mm x 32mm laminated ribs fixed on 144mm x 32mm iroko cross beams at 600mm centres. The planking around the turn of the bilge was chamfered 4 degrees each side. The turn of the bilge to the keel is sealed and strengthened, internally, with a layer of chopped strand mat. The keel comprisesl2mm marine plywood on composite triangular box frames made from two skins of 12mm marine plywood on 75mm x 32mm iroko again at 600mm centres. There is a hog of 144mm x 32mm iroko and his continues up the front and rear of the keel. The decks and seating are in 9mm marine plywood on 44mm x 19mm framing. The spray rail and carlings are 100mm x 19mm iroko. The rudder is made from a composite of fibreglass with a plywood core. The rudder stock is 35mm diameter 316 stainless steel with two pairs of welded tangs. The rudder is secured with 3 16 stainless steel shoe at the heel and at the hull by a 10mm thick fibreglass tube from waterline to deck level. Ballast is 460 Kg of lead internally in the hollow keel. The rig is Z-spars aluminium mast and boom with sails by Jeckells.

This concept inevitably raises many questions concerning the performance of the design/concept with regards to initial stability, what will be the effect of heeling on speed, how comfortable will the motion be through wind induced waves and how responsive will she be to the helm. Without formal training and therefore the means to provide theoretical answers and at the time of writing little empirical evidence I am only in a position to give my views.

Firstly with regards initial stability I believe that as any overturning force pushes the hull into the water this will be resisted directly by pure righting moment as none of the hull on the opposite side comes out of the water as it was never in it. At rest it is possible to walk around on decks with the boat providing a relatively stable platform given the overall beam of 1800mm and beam at waterline of only 1200mm! Under way the beam of the hull, which provides the righting moment, is pushed into undisturbed water as the movement of the hull, in an upright position, does not create the wave pattern that forms a trough in the surface at the critical point of maximum beam. The expected reduction in speed as heeling increases, as is the case with most boats, does not seem to be significant. Given that the turn of the bilge has only a

300mm radius it appears that when heeled the bilge and the keel perform as would two narrow hulls.

I suspected that there would be a significant amount of slamming, given the flat surfaces of my design, however with the narrow beam and fine ends I believe this to be tolerable having sailed through a 'Solent chop' at speeds of up to 18.3 knots in June of this year. We also recorded regular 9's to windward on the same day.

With regard responsiveness of the helm I feel that there is an acceptable 'trade off between speed and manoeuvrability. She has to be sailed around a tack, which is no different to any long keeled boat.

This prototype is just the beginning of a development programme that will seek to reduce wetted area, use a centreboard for improved windward performance, attach a lead bulb to the centreboard to lower the centre of gravity and utilise a modern rudder design to improve responsiveness. If successful in this competition then the prize money would fund these developments. The intention is to build the next boat, the cruiser, using the latest lightweight construction materials.

This concept whilst most beneficial to boats of short length can be scaled up to any size and is of benefit not only for sailing vessels but powered vessels of the displacement and semi-displacement type as used by the military, coast guard and RNLI. I have recently made several contacts regarding partnership arrangements for design licensing and setting up manufacturing facilities but these are very much in their infancy.

The series of photographs were attached to this application as follows:

1. A view of the prototype as it was lifted in to Preston Marina at its launch in February 2001. The hull and keel configuration can be clearly seen in this shot.

4 .5 Photographs showing the prototype tacking past the end of the jetty on Windermere 2002. As can be seen the hull and keel do not produce bow and stem waves even though the stem is dragging somewhat due to the poor weight distribution of the inexperienced crew!

*Michael Wingeatt*
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*Photo 5*

# Simplified Windmill Design for Marine Purposes

Mario Alejandro Rosato

**Abstract**: this paper aims to providing the amateur a simple tool for the design of a windmill using just with a standard PC and an Excel file, avoiding the use of tedious graphical calculations or the need of programming abilities to develop specific software. It's beyond the scope of this paper to present a complete theory of wind turbine design, which can be found in the technical literature. The exposition is mainly practical and explains how to use the Excel tool to design a windmill, its limitations and some design tricks. It doesn't need any technical skills to be understood. A copy of the Excel file is included, for the readers to "play" with it.

The merits of this work to justify its submission are the easy of use and the availability of the Excel software, though providing anyway a good accuracy of results in the range of validity of the tabulated solutions. This Excel table will allow the amateur researcher willing to construct a windmill powered boat to concentrate on the design of the boat itself, letting to the program the burden of the windmill calculation. Also boat owners willing to self-construct a customised wind power alternator will find this tool very valuable. In principle, there's no power or wind speed limitation for this mathematical model, although the author considers that turbines of more than 10 kW should not be constructed by amateurs without the help of an engineer, since material resistance and safety becomes an important issue at these size levels.

## Detailed description

The analytic design theory of windmills has been known since 1929 and was developed by the German researcher Glauert, who intended to improve the performances of aircraft propellers. The literature on the subject is quite abundant but it tends to be either too "theoretical" for the average amateur reader, or too general to allow the practical design of a wind turbine. The innovative concept for the amateur designer is the use of a standard electronic data sheet (Excel) for quickly designing and evaluating the performance of a horizontal shaft windmill, avoiding the need of writing specific software. Theoretically, Excel could not be used for this scope, because one of the main problems in windmill design is solving a pair of coupled transcendental as "infinitesimal". The practicality of this approach is evident: it's useless to develop a software which is able to calculate the pitch at each point of the windmill's blade with 0,00000001° error if an amateur builder can hardly achieve precisions of 0,5° order or even worse. On the other hand, the performance prediction can easily be done by reversing the entry of variables, as will be seen in Part 1. This goal cannot be achieved with the use of available abacus (see Le Gourière's book), which is suitable just for design.

*[Mario also provided a disk with an Excel program. Copies of this program can be obtained by email from Catalyst@fishwick.demon.co.uk. - Ed]*

## 1. Some definitions

Throughout this paper you'll find a lot of terms specifically related to the windmill "slang". **To make things clearer, it's better to introduce them at the beginning.**

**l** = tip speed / wind speed (non dimensional factor)

**s** = solidity factor = area of the blades / area of the rotor

**blade** = each of the airfoils composing the rotor

**Cz** = lift coefficient of an aerodynamic profile

**Cx** = drag coefficient of an aerodynamic profile

**local pitch** = is the angle formed by the chord of each blade section considered and the plane of rotation of the windmill.

**pitch** = in this context means "pitch of the blade", i.e., the angle by which the blades are rotated around their longitudinal axis from their "nominal" position.

**total pitch** = local pitch + pitch

**torsion law** = is the variation of the local pitch along the blade, that makes it look twisted.

**chord law** = is the variation of the different sections' chords along the blade.

**V** = wind speed across the rotor. It will be the true wind speed if the boat is anchored, and the apparent wind speed if it is moving.

**step** = is the incremental discrete value assumed for calculation purposes as being "infinitesimal".

**N.B.** All formulas in the present tool are intended to be used with coherent Metric Units (speeds in m/s, power in W, lengths in m, moments in N.m, etc.). Where "technical" units are used as input (like the rotation speeds in R.P.M and the angles in º), the cells are already programmed to convert them (for instance in radians/s, and in radians).

## 2. Main features and limitations of the calculation tool

The submitted Excel file allows the amateur to easily design, analyse the performance and build a horizontal shaft wind turbine, either for driving an alternator or a propeller. It provides a good accuracy of results but some limitations must be kept in mind:

2.1 The profile chosen is NACA 0012. This choice was dictated by the fact that the author has aerodynamic data for this profile also beyond the stall point. This is a very important feature for the analysis of the windmill's performance, since, unlike an aircraft propeller, a windmill must operate in a wide range of speeds. It's difficult to find such data for other profiles. Furthermore, NACA 0012 is a symmetrical and easy to build profile. With negative angle of attack the Cz value is the same of the positive case, but with opposite sign. The Cz and Cx data of the profile were tabulated with a step of 0,5º through linear interpolation in the "usual" range of angles of attack. In the stall range and over, the precision is lower (data derived graphically and furthermore linearly interpolated!). In some cases it's possible that the table displays efficiencies over 100%. This error has its source in the rounding of the aerodynamic data. You can ignore this results and assume that the real operating output power will be about 5 to 10% lower than the calculated value.

2.2 There's another source of error, which will be evident while eventually testing a model designed with this tool: Cz and Cx vary with the Reynolds number, especially when operating in the stall range. The tabulated data are valid for Re = 1,8 x $10^6$. This means that for weak winds and/or low speed rotations the real output could be much lower than the calculated one. In the upper speed range, the influence of Re is not so big.

2.3 Of course you can use other profiles than NACA 0012. You must just change the corresponding table, but keeping the same tabulation step.

2.4 The range of validity of the l factor is

$$0{,}01 < l < 13$$

Out of this range, the results will contain significant errors.

2.5 It is assumed that the first quarter of the blade will have no profile, although the aerodynamic drag of this portion (usually a tube) is not considered in the calculations.

2.6 The remaining 75% of the blade's length is divided into 30 points. So a discrete integration with a small step (2,5% of the total rotor radius) is performed. Please, note that for a windmill having 1 kW output, this means that each "delta" is about 4 cm long, and the author considers that precision should be enough up to 10 kW power. If more precision is needed, the step value should be changed accordingly, and more rows could be added with the "copy down" function.

2.7 Negative torque and power means that the incidence angle on the profile is negative. In this condition the blade is acting as a brake instead of producing power (we'll see why this feature is useful in some cases).

## 3. The usual design cases

The main usual marine applications of a windmill are:

3.1 Electricity generation (for battery charging, feeding the general services; for heating, ventilation or drying purposes; for navigation comfort in general). In this case it is necessary to know the output vs. speed curves of the alternator (not very critical if you will rectify the AC to provide 12V or 24 V DC). We must somehow be sure that all the output will be absorbed by a load (battery and eventually a shunt resistor with a fan, which could help to keep the boat's interior dry and ventilated). This condition is necessary to avoid the rotor accelerating without limit (or almost) with increasing wind speed. Any kind of speed limiting device is highly recommended.

3.2 Propulsion (either by driving a propeller or a water jet through a suitable transmission system). In this case the propeller's curves must be known prior to choosing the design parameters of the windmill, although the author personally considers that horizontal shaft wind turbines are not the best choice for propulsion purposes (a Darrieus-like turbine would be simpler and lighter).

3.3 Mixed (alternator feeding the batteries and general services and driving a motor for propulsion). This third case is rather theoretical: a big alternator driving a big electrical motor means double weight, plus a very robust (and hence heavy) mechanical transmission from the mast top to the bottom (or as alternative, mounting the alternator at the top of the mast, thus creating stability problems). The overall cost of such a boat would also be higher than usual.

3.4 In all cases it is very likely (not to say sure) that a multiplication gear between the turbine's shaft and the generator or propeller will be necessary. You must then consider from 20 % to 40% of mechanical energy loss.

## 4. Data needed to start the design

The input data which you need to choose will be then:

4.1 Nominal power – The output you want to obtain at the shaft of the turbine.

4.2 Nominal wind speed. – The wind speed at which the turbine will be rotating at its nominal speed and providing its nominal power. Depending on the place and weather conditions where you use to sail, nobody better than you can have the "feeling" of which wind speed is more likely to be encountered. This choice is quite critical since the power for a given diameter varies with the cube of the wind speed. Hence, to provide 1000 W at the shaft in a 6 m/s wind will need a rotor of about 5 m diameter, while in 8 m/s only 3 m diameter would be needed. The author would recommend a nominal wind speed of about 8 m/s (Force 4 in the Beaufort scale). Also consult your nautical base, since many of them keep records and statistics of the wind speeds.

4.3 Nominal λ and number of blades. – If you intend to drive an alternator or a centrifugal pump for a water jet (high speed, low torque) high λ values (6 to 10) and 2 to 3 blades will be required. Driving a slow propeller (low speed, high torque) will require low values of λ (2 to 4) and a high number of blades (8 or more). There are theoretical and practical reasons for this: the solidity factor σ, λ and the ratio Cz/Cx of the chosen profile are interrelated. The calculation tool provides some hints for choosing λ and the number of blades.

4.4 Operating point of the profile. – This is a question very hard to answer, since it depends on what you are willing to develop. For instance:

4.4.1 Choosing low values of α (angle of attack) means designing with low Cz. Such a rotor has the advantage that with increasing speed (λ) the angle of attack will diminish, even becoming negative, so there's a certain self-limitation of the rotation speed, especially if the profile is symmetrical, because it will provide a breaking torque when accelerating over the nominal λ. The axial loads on the structure will be lower, because low Cz means also low Cx. The disadvantage is that the blades will have big chords (you need more area to obtain the same driving force with low Cz), sometimes becoming unpractical or impossible to produce.

4.4.2 Choosing the highest Cz means approaching the stalling zone, with higher loads on the structure. Suppose the rotor is turning in nominal conditions and a gust comes, then λ will have a transient low value, thus α will be higher and Cz and Cx will be lower. Theoretically this should reduce the output power, but at the same time the available power of the wind is rising (remember it rises with the cube of the wind speed). The result is that the energy of the wind grows faster than the aerodynamic performance degradation of the airfoil, so the power at the shaft could be anyway higher than the power that the load can absorb, thus accelerating -almost- without limits the rotor.

4.4.3 Some authors counsel choosing as the nominal operating point the angle of attack α at which the ratio Cz/Cx is maximum. This is usually a good compromise for aircraft propellers, since the rotor will work at its best efficiency. But windmills, unlike aircraft propellers, must work in a wide range of wind speeds and rotation speeds. A blade designed with this criterion will need absolutely a device varying the pitch with the rotation speed, or some sort of aerodynamic brake, or any system to avoid the rotor being overdriven (what would compromise the structural integrity of the machine and the safety for people).

## 5. Beginning to use the tool: a simple example

The file windmill-design.exe you will see consists of 7 data sheets: "pre-design", "analysis 1", "analysis 2", "pitch-reg", "self-reg", "solu-lambda" and "C-NACA12".

Suppose we want to design a windmill to drive a small car alternator with nominal output 800 W. We assume 20% losses, so the required output at the shaft will be 1000 W. Please, enter "1000" in the corresponding cell. Suppose that the chosen wind speed is 8 m/s, so enter "8" in the corresponding cell. Since we need a quick machine, we'll choose l to be 7 and the number of blades to be 3 (because such a rotor is easier to balance than a single-blade or a two-blade rotor). We'll assume the criterion of the maximum aerodynamic efficiency. Please go to the C-NACA12 sheet and have a look at the corresponding table. You'll notice that for a NACA 0012 profile this is achieved at a = 13º. So please enter "13" in the corresponding cell, and the related values of Cz and Cx. Done! You've designed a windmill the shape and dimensions of which are optimised for the nominal conditions!

The results will be:

Diameter = 3,13 m
Rotation speed = 242,25 R.P.M.
Output power = 959 W
Total torque = 27 Nm
Axial force = 270 N (relevant for checking the resistance of the mast and the heeling of the boat)
Aerodynamic efficiency = 64,78 % (not bad for an all-purpose profile)

The graphic below the calculated values shows you the approximate shape of the blade (not in scale), and its load diagram, which you will need to check the structural resistance. The columns P and R display the loads at each section of the blade. In this example, the tangential loads are about 1/10 of the axial loads, so we won't consider them. Please, note this may not always be so, specially if working in the stall range. In our example, the maximum nominal load will be about 100 Nm. You can dimension the structural component of the blade (usually an aluminium or steel tube) with the help of the classical formula:

$$\sigma = M_{max}\, y / J$$

(which becomes $\sigma \approx 10\, M_{max} / D^3$ for a full circular section of diameter D and

$\sigma \approx 10\, M_{max}\, D / (D^4 - d^4)$ for a tube with internal diameter d)

or with tabulated values usually published in technical handbooks. Structural analysis is beyond the scope of this paper, but just for didactic purposes, the load calculated (≈100 Nm ≈ 1000 Kg.cm) would be resisted by a steel tube of 5 cm diameter and 3 mm thickness, with a safety coefficient of about 4.

A windmill always needs a tail to keep it facing the wind. The tail's area is calculated with an empirical formula and the sketch is shown at the right of the load diagram.

## 6. Further uses of the tool: analysing the performance of the rotor.

Now you have designed the rotor for a certain wind speed, you may want to know how it will perform in a given range of the wind speeds. This is absolutely necessary to decide which speed regulation -or limitation- system to adopt. Following our example, please open the sheet named "Analysis 1". You may want to make several copies of it in order to analyse different systems. This sheet is linked to the "pre-design" one. The formulae are the same, but some columns were added because by varying the speeds, a will vary and hence Cz and Cx, thus changing the torque and output power. So an Excel function will choose the proper values of Cz and Cx at each step of the blade from the table C-NACA12.

Now, look at the "optimum" blade shape calculated in "Pre-design". You'll notice that the chord should be about 13 cm at the root and 9 cm at the tip, with local pitch angles of each section varying between about + 7 º to –7º. This shape may be somehow difficult (or expensive) to be built by an amateur, so let's suppose we'll decide to make it straight and with no torsion. The chord will be 20 cm all long the blade, and the pitch will be in principle 0º. Please, copy these values in the corresponding cells (already done in the annex file, in the sheet called analysis 2). Now, let the wind speed value fixed at 8 m/s and vary the rotation speed from 0 to the mechanical limit you may decide for your rotor. Then, copy each value of the power and rotation speed in the table below, and you will obtain a curve like the one shown. In this case, there's a negative portion in the low speed range, meaning that the supposed rotor will have some trouble in starting operation. You should suppose a pitch, for instance + 3º, and write it in the corresponding cell (B13), and then repeat the test for all the speed range and for different wind speeds. You will obtain a family of curves similar to the one shown. With the data obtained, you can then decide how must the pitch vary as a function of the rotating speed in order to provide a more or less constant output and rotation speed. The Author has included just an example, which you could make more complete by adding more curves to the family. Just notice that obtaining 1000 W at 8 m/s and 10 m/s would require that the pitch of the blade is 0º and its rotation speed about 180 R.P.M. at 8 m/s, while at 10 m/s you'll need to vary the pitch to 8º to obtain 1000 W at about 200 R.P.M. (for instance, with a centrifugal mass acting on the blade through a conical toothed wheel).

## 7. The control through pitch variation

Let's now make an example on how to design a pitch variation system. Again, we'll open "analyse1" and make a copy of it, which in the example file is called "pitch-reg". As usual, this is linked to "pre-design" but you could also change the torsion and chord laws (cells H30:H60 and J30:J60) as in the first example. We'll arbitrarily keep the chords and local pitch angles from "pre-design" and impose a linear speed variation law with increasing wind speed. We want the rotor to keep its rotation speed within a range of 263 RPM at V=2 m/s and 333 RPM at V=16 m/s. Of course the power must remain near the nominal output of the generator. So, start by setting cell B11 at the highest wind speed 16 m/s. Set the cell B12 at 333 RPM. Now, try different values of pitch until the output power will be near the nominal 1000 W. You'll find that 2,7º or 2,8º fit this condition. Now repeat the play for the other wind speeds, and you'll find the pitch angles of the blade that fit your design requests. In this example we tried to obtain a pitch variation law that has more or less linear results. Now is up to your creativity to design a mechanical system that will move the blades varying their pitch following the desired law. HINT: if you intend to design a pitch variation system based on a centrifugal mass as actuator, keep in mind that the centrifugal force increases with the square of the rotational speed, so it would be better to search for a pitch variation law of quadratic type.

## 8. Advanced design: the self-regulated rotor

We'll explore the potential of the so-called self-regulated rotor. The idea is to analyse the output of single blade with fixed pitch as a function of wind speed, and then make a rotor in which the 3 identical blades are mounted with different pitch in order to compensate the output power (with strong winds, one or two blades would be braking the other). These rotors are suitable for driving alternators which will then provide 12 V DC, since they don't require a critical control of the speed (think of your car's alternator, it will provide useful output within a range of 900 to 4500 R.P.M.). They are interesting for the amateur builder because they don't need complex gears for varying the pitch. The disadvantage is that they may create pulsating loads and hence vibrations, so the structures should be designed with higher safety coefficients. Also the calculation method is more tedious (just trial and error until convergence is found) but the result may be worth of it.

Now, please open your tool and click on the sheet called "self-reg". This one is linked to the "pre-design" (it's just a copy of "analysis-1"). This time let the shape and torsion of the blade be the same as in "pre-design" (you may also define your own shape and torsion as we did in the example before). Now, change the number of blades to "1" (cell B5), impose a nominal rotation speed, say, 300 R.P.M. (cell B12), and then tabulate the results you will obtain by varying the wind speed and the pitch, as shown in the example table. You will notice that for a given pitch and rotation speed, the power output varies with the wind speed, having ranges in which its values are negative. This means that a blade made to rotate at that speed and in that wind will dissipate energy instead of extracting it.

You must then find a combination of 3 blades that provides the flattest output curve, not exceeding the nominal power output in the desired range of wind speed (remember that exceeding the nominal output will cause the rotor to accelerate, maybe up to dangerous speeds if the output doesn't diminish with increasing speed). In our case the best combination seems to be the yellow curve (but you should also analyse what happens with intermediate pitch angles like –1°, 1° and 3°, maybe they are even better!).

Now that you have chosen a potentially good combination, you should refine the results by determining the output of each blade as a function of the rotation speed for each wind speed, add each single point and obtain the total operational curve of the complete rotor. This is shown in the following table, where you can see the power output for different wind and rotation speeds.

The windmill's performance curve will pass through the green marked values. You may ask yourself why. So, imagine that the rotor is stopped and the wind begins to blow at 2 m/s. The rotor will begin to accelerate and it will reach an equilibrium somewhere over 100 R.P.M. By no means it could turn faster because it can't give more power than the theoretical obtainable with that size and wind speed, which in this case is 23 W. If the wind now increases its speed, the rotor will accelerate up to about 210 R.P.M, and so on until the wind surpasses the nominal design speed. At this point the acceleration of the rotor will bring an increase in output, thus accelerating further the rotor (values marked in red). This means that the chosen combination is not yet the optimal throughout the whole range of wind speeds (unstable). We must find a combination that provides decreasing power output with increasing wind speed (i.e. at least one blade should produce drag instead of driving force). The process should be repeated again, maybe by refining the combination (try for instance a combination of 3 blades with –4°, 2° and 4° pitch angles), or imposing also the rotation speed variation with the wind speed instead of just assuming a fixed speed of 300 R.P.M. over the whole range.

## 9. Conclusions

There's an enormous number of factors contributing to one design option or to the other when you start designing a windmill from a scratch. As you've seen, the tool presented is flexible enough to allow considering most of them. Always check the loads on the blade for every wind / rotation speed, and design them to resist the worst of them with a certain safety margin, (the Author would counsel at least 2). The Author hopes that this work can help the readers to make their boats more comfortable by having more energy at disposal with a custom made windmill. And for those willing to build a windmill driven boat, that they will better design the rotor to fit the propeller's characteristics, thus improving the overall performance of the boat herself. It's probable that the performance of the windmill driven boats constructed till now may have been inferior to their true potential, just because the windmills used were in general commercial models meant for electricity generation and not for boat propulsion. Anyway, enjoy and have fun with the wind!

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| | | | | | | |
|---|---|---|---|---|---|---|
| **PRE-DIMENSIONING THE WINDMILL** | | | | | | |
| | | | | | | |
| **INPUT DATA** | | | | Hints for choosing λ and the number | | |
| NOMINAL POWER | 1000 | W | | of blades as a function of Cz/Cx | | |
| NOM.WIND SPEED | 8 | m/s | | Cz / Cx | λ = | nr. of blades |
| N° OF BLADES | 3 | | | 5 | 0,5 to 1 | 24 to 12 |
| PROFILE | NACA 0012 | DIFFICULT | | 20 - 40 | 2 to 3 | 12 to 8 |
| Cz = | 1.426 | DECISION, PLEASE | | 40-50 | 4 to 5 | 8 to 6 |
| Cx = | 0.018317 | CHECK PAPER | | 60 - 100 | 5 to 7 | 6 to 4 |
| α = | 13 | FOR HINTS | | over 100 | over 7 | 2 or 3 |
| Cz/Cx = | 78 | max. Cz/Cx for this profile ! | | | | |
| Nominal λ | 7 | 0,1 < λ < 13 | | | | |
| | | | | 3 or more blades are easier to balance | | |
| | | | | | | |
| dR | 2.500% | of R | | | | |
| (calculation step, if you decide to change it, the number of total steps must be changed acco | | | | | | |
| | | | | | | |
| | | | | | | |
| **OUTPUT VALUES** | | | | | | |
| | | | | | | |
| DIAMETER | 3.13 | m | | | | |
| ROTATION SPEED | 342.25 | R.P.M. | 35.84 | rad/s | | |
| induced Cx = | 0.04312443 | **Cxi = Cz$^2$ / (π * 0,85 * AR)** | | | | |
| M tot = | 27 | Nm | | | N.B. 0,85 is the Oswald | |
| P shaft = | 959 | W | | | Factor for non elliptic | |
| F axial shaft= | 270 | N | | | planforms, and AR is the | |
| Aerod. Efficienc | 64.78% | | | | approx. Aspect Ratio | |

*The opening page of Mario Rosato's Windmill Design spreadsheet.*
*This program is available by email from Catalyst@fishwick.demon.co.uk*
*The program is written for Excel 2000, but neither AYRS nor the author can guarantee that it will run on your computer or that the results will suit your application.*
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# Twin Jib Rig for Strong Winds

Michael Collis

Sailing downwind in strong winds and rough seas, the mainsail of a sloop may cause a broach and the boom is a menace in an involuntary gybe. A much more seamanlike rig is a pair of jibs which can be handled as a single sail, the boom being lashed to the toe rail.

Such a rig has, I believe, been developed for boats with twin forestays. My rig enables two jibs to be hoisted on a single stay. It may be a re-invention.

The sail area of Gentle Jane, our Red Fox 200E, is 200 sq ft (18.6 sq m ). The jib is 70 sqft (6.5 $m^2$), thus two jibs total 140 ft2 (13 $m^2$) i.e. 70% of normal (less if reefed).

I had a second jib made. It had to be 1% larger than the original because sails shrink with age. The forestay hanks are staggered so that they alternate with those of the original. It also has a single reef (Print 2).

Both jibs are hoisted on the same halyard, the peak cringles being connected by a short line rove through the halyard cringle. This line has a long tail to attach to the new jib's peak when it is reefed. The halyard luff tension is of little consequence downwind. The tack of the new jib is held by a lashing, which is adjusted so that both peaks are at the same height.

*Rig on port gybe*

*Print 2 – Spar & joining sleeve*

The clews are held apart by a spar made of a wooden and an aluminium telescopic boat hook, joined by a metal sleeve which is divided by a rod at mid-length (Print2) The sleeve is captive to the mast; the boat-hooks will have to be likewise.

The sheet arrangements are normal, except that they are attached to the clew cringle by Bubble knots (Practical Boat Owner 403, page 63), for rapid transfer in heavy weather.

A trial in light wind shows that the rig will stand with the wind nearly on the beam. Should it be necessary to come on the wind in a hurry, the spar is removed and the windward jib simply lies flat against the leeward one.

It may prove impossible to unrig the spar in a strong wind. If so, it may be necessary to redesign the sleeve so that it can be released to fold in the middle.

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*Running. Note alternate hanks*

*Rig on starboard gybe*

Illustrations:
- Print 1 – Rig on port gybe
- Print 2 – Spar & joining sleeve
- Rig on starboard gybe
- Running. Note alternate hanks

# Some thoughts on Junk Rig Performance

Slieve McGalliard

The following notes were written in an effort to analyse available information as it applies to the windward performance of the westernised version of the Full Battened Chinese Lug Rig. They should be viewed as a personal interpretation as required for a particular set of problems. The diagrams below are either based on the diagrams of others or on best assumptions based on their results. The author is keen to receive criticism of these thoughts in an effort to open a debate and expand the pool of knowledge.

## Basic Thoughts.

Since the first Single Handed Trans-Atlantic Race significant effort has been made to improve the performance of the Chinese Lug rig, yet it is still seen as being over complicated and to have poor windward ability. Unfortunately comparisons are usually made with highly tuned Bermudan rigs as used on America's Cup boats, which have large well-trained crews and extensive sail wardrobes. No effort is taken of more realistic comparisons with family cruisers, where an elderly roller Genoa with a poorly set sheeting position will also produce poor windward performance, and which will be even less efficient as the wind frees. Until a boat with a fully battened lugsail produces a remarkable performance in some much-publicised popular event interest will stay low, leaving just a few enlightened enthusiasts to enjoy the many benefits.

The quest is to produce an easily handled rig for a lightly crewed cruising boat that will have equal or better performance than a cruising Bermudan sloop on all points of sailing. Inevitably this means concentrating on the windward performance.

## Basic Hydrodynamic Theory

Figure 1 is a simplified diagram of the forces involved in the close-hauled situation. $F_T$ is the total aerodynamic force produced by the wind in the rig, and can be resolved into $F_R$ along the track sailed, which drives the boat forward, and $F_H$ perpendicular to the track sailed, which causes the boat to heal and make leeway. $R_T$ is the total hydrodynamic force which is equal and opposite to $F_T$, which can be resolved into $F_S$ which resists leeway, and is equal and opposite to $F_H$, and R which is along the track sailed and is equal and opposite to $F_R$.

As the wind gets stronger it pays to reef to reduce the heeling force $F_H$ to keep the boat moving at its best speed. As reefing reduces the total air force $F_T$ it also reduces $F_R$, the driving force. This implies that simply increasing the total force $F_T$ will not necessarily increase the boat speed, and as the wind gets stronger an increase in $F_T$ will actually slow the boat below its best speed.

The simple answer to improving speed to windward must be to increase $F_R$ without significantly increasing $F_H$, which is the same as swinging the vector $F_T$ forward towards the bow

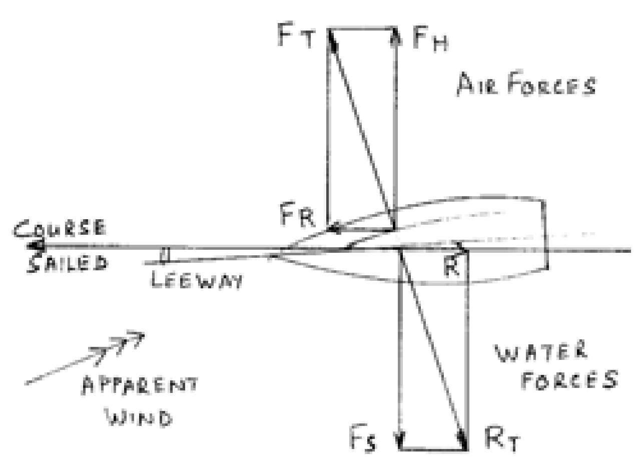


*Figure 1*

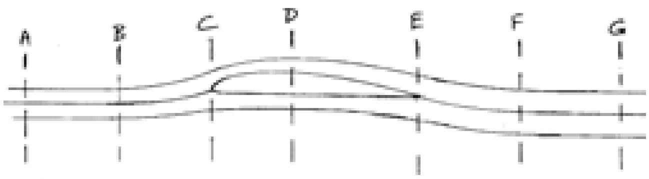


*Figure 2*

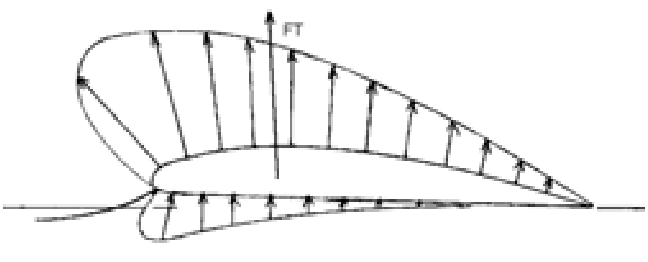


*Figure 3*

of the boat. The question is how to find a simple solution to this simple problem.

## Basic Aerodynamic Theory

It may be helpful to look at the aerodynamic forces involved to find an answer to the ‘simple’ problem. Figure 2 shows the airflow around a simple flat-bottomed airfoil of the Clark Y type, and Figure 3 shows the forces involved. Admittedly thick airfoils are somewhat different to sails, but this diagram should make the situation easier to grasp.

In Figure 2, between A and B, the air approaches the airfoil with the streamlines straight and parallel. From B to C the presence of the foil is first sensed by the air, which produces upwash (of which more later). At the stagnation point C the flow splits and the air going over the top accelerates over the curved leading edge and the pressure drops. The flow that goes below the foil slows and the pressure increases. After E, the flow is deflected, but by F it will return to its original direction but with energy removed.

Figure 3 shows the pressure pattern affecting the foil. As pressure can only exert a force perpendicular to a surface, the force vectors will always act at right angles to the curved surface of the foil. The total force produced is the vector sum of all the vectors for each unit of area, and is the total force $F_T$ referred to earlier. Rather than add all the force vectors it is interesting to divide the foil in thirds and add the vectors for each third separately. Although not accurately drawn, Figure 4 shows that it is the sum of the vectors from the first third of the foil, Fa, which produces the desirable forward directed force. This shows that it is the first third of the foil that is the most important for sailing to windward.

Figures 2, 3 and 4 show the impressive performance of a thick asymmetrical airfoil, and suggest that a wing sail should perform well. Unfortunately a single ply sail cannot have a thick leading edge, with the stagnation forced round to the lower side by the upwash and the air accelerating over the leading edge, which produces excellent windward drive. With a sharp edged sail the leading edge must exactly point into the airflow as it strikes the sail or a separation bubble will develop which will greatly impair the pressure development. Therefore the best a single ply sail can do is to produce a force vector at right angles to the upwashed stream.

Figure 5 is an effort to show that the single ply sail can still produce useful ‘forward’ thrust provided that the first third of the foil is well cambered and that the sail starts to curve as early as possible to develop the suction at the front of the sail where the vectors will point furthest forward.

(In chapter 17 of his book High Performance Sailing, Frank Bethwaite gives very clear descriptions of the flow and pressure distribution around sails, and makes essential reading for students of sailing performance.)

## The Effect of Upwash

In Figure 2, between B and C the airflow starts to curve up as it approaches the foil. With a sharp edged sail it is important that the air meets the sail exactly in line or separation bubbles form. The more upwash the higher the sail can point to the relative airstream A to B, and as VMG to windward is the cosine of the angle between the true wind and the track multiplied by the boat speed then any increase in the upwash will improve VMG. The air approaching the sail cannot anticipate the sail, but can only react to the pressure pattern produced by the sail. The airflow can only be upwashed by the low pressure above and in front of the leading edge

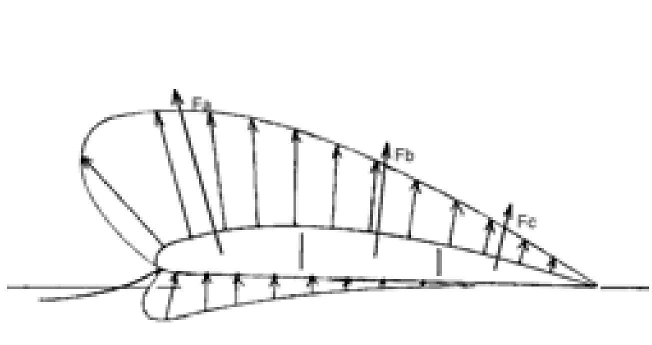


*Figure 4*

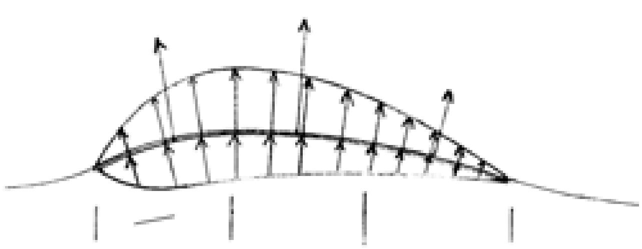

*Figure 5*

of the sail. Therefore achieving good suction at the leading edge is doubly important as it not only helps boat speed, but by promoting larger upwash also helps by reducing the tacking angle. If the first third of the sail is flat (as on many existing junk rigs) and the low pressure is not formed until a third of the chord from the leading edge the low pressure will have no significant effect on the approaching air and there will be no significant upwash, and therefore a large tacking angle.

All this infers that the solution to the 'simple' problem referred to earlier is to build a good camber into the first third of a sail, and encourage the airflow to follow the curve.

## Practical Examples

So how does this 'simple' answer fit existing practical Junk rig experience?

Despite achieving significant improvements in performance on his boat *Felix*, Bunny Smith (in Junk Rig Association (JRA) newsletter No.26, page 22, para. 8) pointed out that his Junk rig still under performed to windward. He illustrated this with a sketched polar diagram. In para.18 he stated that when designing the Felix sail he decided on the basis of his airflow observations, sailing experience and aerodynamic knowledge that *all sail area ahead of, in way of, and for one foot aft* of the mast should be ignored in deciding the lead of the CE over the CLR. This infers that the forward area of the sail was having no significant effect. He actually moved the mast 3 feet forward (11.5% LOA), and raked it forward. Apparently this corrected all the handling problems and the boat then became perfectly balanced. This ties in with his diagram in JRA newsletter No.20, page 16, where he shows a large separation bubble covering the first third of the lee side of the sail. It's interesting that Joddy Chapman also found leading edge separation bubbles were predominant in his Junk rig experiments.

In stark contrast Frank Bethwaite, in his book High Performance Sailing, in Fig. 17.28 shows a modern wingmast with turbulent flow immediately reattaching, eliminating the separation bubble and establishing attached turbulent flow right from the front of the curved sail. At the end of para.17.10 he states that when they started to get the wing masts to work the boats all developed lee helm. They had to move the centreboard forward a foot or more (> 7% LOA) to balance the *powerful suction close behind the mast* (at the luff of the sail). This is the exact opposite to Bunny Smith's experience.

With the separation bubble over the flat first third of the sail the Junk rig under-performs to windward whereas the wingmast with attached turbulent flow over the first third of the cambered sail actually helps the dinghy plane to windward!

There are many other examples of the importance of the flow over the first third of the lee side of a properly cambered sail. Without a tight luff the jib of a Bermudan rig looses its designed cambered sail shape and flow, and its windward performance deteriorates. A partly reefed roller genoa also has very poor sail shape and performance to windward is much worse than if using a smaller hanked on sails. An old stretched genoa, with the camber blown aft will not point nor foot well to windward.

Without good suction near the luff of the Junk sail there is less upwash than with the Bermudan rig and therefore a wider tacking angle.


*Figure 6*

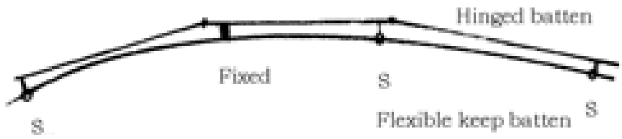


*Figure 7*

## An Apparent Conclusion

The above would suggest that until a method is found to build a properly cambered leading edge and achieve flow to the lee side over the first third of the sail then the Junk rig will not perform well enough to windward to sway the sceptics. Conversely, if this can be achieved then when combined with its other virtues, the Junk rig could embarrass quite a few people and achieve a large following.

## An Examination of the Present State of Art

All the above suggest that a flat, uncambered sail will not perform well to windward. The early Hasler/ McLeod rig performance agrees with this, with poor drive and large tacking angle due to lack of upwash.

All the newer, better performing Junk sails employ camber, either from flexible battens, hinged battens or stiff battens with broad seam built into the sail. Unfortunately the achieved camber does not always extend forward to the luff. There is now some news of experiments with pre-bent battens with double skinned sails, which could prove to be very interesting.

Flexible battens have the known disadvantage of bending more as the wind gets stronger, which is far from ideal. The forward section of the batten, in front of the mast, also tends to bend the wrong way and show no potential to easily produce the desirable camber and attached flow suggested above as required for good windward performance.

Hinged battens have the advantage that the camber is constant over the full wind speed range. Unfortunately the first 30% of the batten has to be stiff to prevent the batten hinging the wrong way which does not encourage the development of high suction forward to get the forward directed force and strong upwash desired.

Stiff battens with panels shaped by rounding or broad seam, according to Arne Kverneland (JRA newsletter 30, page 21) does seem to show some advantages, and some weaknesses. This set-up does not produce an ideal smooth airfoil surface but does have camber right to the leading edge at the middle of each panel when on starboard tack. Arne claims that the rig tacks through 90 degrees and gives good balance. It would be interesting to fit instruments to see if the performance on starboard tack is significantly better than on port. It would appear probable that it is, and if this could be achieved on both tacks then the performance may be very interesting, particularly if the broad seam at the luff could be carefully tailored.

In JRA newsletter no. 31, page 14, Arne also stated that using hinged battens 'gave some increased weather helm.' This would suggest that the centre of pressure was positioned quite far aft in the sail, and not in the first third. Referring to his straight battens/ cambered sail in JRA newsletter no.30, page 24, he wrote that 'he had to pull the sail a bit aft to avoid lee helm' which would suggest that the first third of the sail was producing good drive. (This would tie in with the better performance achieved with Frank Bethwaite's experience with the wing mast.)

Of the 4 types mentioned above, stiff flat, flexible, hinged and stiff with shaped panels, the latter seems to be the only one able to produce camber in the forward third of the sail at the present state of the art. It may be that best performance will eventually be achieved by combining types, such as hinged battens with broad seam shaped panels over the first third of the sail, or between the straight sections of the battens, as in figure 6. Alternatively, fitting the sail to very flexible 'keep' battens attached by spacers to structural hinged battens may achieve a desirable smooth camber in the sail, even into the first third of the sail. In figure 7 the battens are joined with a fixed spacer at F, and sliding spacers at S.

Considering the amount of shaping required with Bermudan sails, and even with rigs like the Standing Lug it is asking a lot to expect a flat cut sail to perform well in a Junk rig, even on bent or hinged battens.

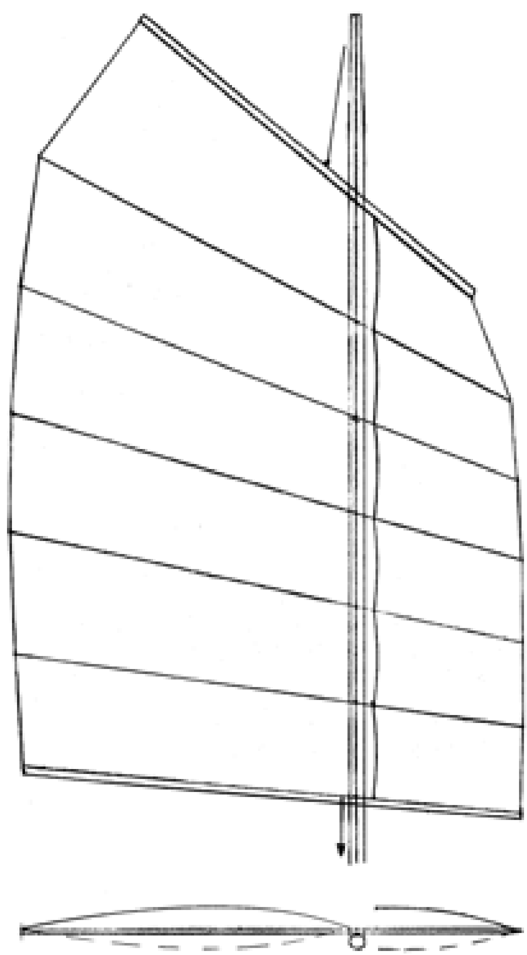

*Figure 8, not to scale.*

Rather than follow existing forms it may be worth considering some of the reasons behind the various features in an effort to obtain a better modern day solution. Features worth examining could include 1) batten angle, 2) yard angle, 3) sail outline, and 4) sail balance.

**Batten angle**. Although many think of the air flowing from luff to leech as being horizontal it must be remembered that in producing lift the high pressure air will blow up the windward side of a sail and the low pressure air on the leeward side will blow downward, and producing a vortex behind the sail. The lower the aspect ratio the more pronounced this 'span wise' flow will be. Bunny Smith was keen to promote turbulent flow on the lee side of the sail by 'tripping' the air over the battens. It may, however, be more important to accurately align the battens with the airflow on the windward side to provide a free uninterrupted journey across and up the sail, and not to 'trip' and lower the pressure of the high pressure air. Streamers or smoke may show the ideal batten slope on the windward side of a well cambered sail.

**Yard angle**. It seems to be generally accepted that the longer the luff the better the potential performance. This has produced long yards angled as near to the vertical as possible, like a Gunter rig. Modern airfoil design is paying more attention to efficiency by pushing the tip vortex as far out and aft as possible. A shorter less acutely angled spar may be more effective if fitted to a sail with a longer luff, by sweeping the actual tip further aft and encourage the vortex to flow from the extreme tip. A less acutely angled spar may even produce an efficient leading edge vortex as developed with the Crab Claw rig. As Tony Marchaj has pointed out, nature seems to like swept tip foils, so possibly evolution should be worth copying.

**Sail outline**. It would appear that all sail outlines are being drawn with a straight luff, with the sail needing adjustable luff parrels or Hong Kong

## A Sideways Thought

The above mention superior performance of wing masts would suggest that the thick forward section of the Swing Wing Rig, with the mast enclosed by the sail, has huge potential. It is a pity development did not continue as it would appear that a simple fundamental design error may have marred an otherwise very good rig.

## Some Thoughts on a Different Vein

At the moment there are a number of different outline sail-plans being used. Some are based on the early Hasler/McLeod designs, others on the Felix form, and some on Vincent Reddish's observations.

parrels. Vincent Reddish reminded us that the original Chinese method of making the sail was to make the framework of boltropes and battens, and fastening the material to the tensioned framework. If this is done the tension in the angled leech boltropes will push the battens forward and will have to be balanced by the tension in angled luff boltropes pushing the battens back. This will produce a convex shaped luff, and if this shape is built into the sail then the requirements for luff and Hong Kong parrels may be reduced or eliminated. On the subject of Hong Kong parrels, which are required in current designs to keep the boltrope/ batten structure in shape when slack cambered sail panels are attached, the Chinese fitted the parrels at the luff. There does not seem to be any reason why they could not be fitted further aft or even towards the leech to cause less interference and allow better sail camber at the luff, or even eliminate them with better design.

**Sail balance**. Since Bunny Smith found it desirable to pull the sail as far back as possible with the flexible battens of his Felix rig it is notable that all rigs have been pulled back for windward work. If camber can be induced in the first third of the sail then it may be desirable to place as much of the sail as possible forward of the mast to achieve as much beneficial forward thrust as possible. Such increased balance in the rig could produce many desirable side effects, as mentioned later, as well as softer tacking and jibing. The mast could also be stepped further aft in the hull, which could have structural advantages.

## Some resulting thoughts

All these thoughts lead towards a different sail shape based the most promising features, which would appear to be –

1. Stiff battens, with broad seam to produce camber right to the luff
2. Maximum clear cambered area in front of the mast to maximise the desired forward thrust
3. A convex luff to balance the convex leech forces and simplify the rig
4. A long luff with a moderately angled yard to push the vortex as high and as far aft as possible

As the mast will spoil the sail camber on port tack, it would seem logical to split the sail around the mast and end up with a 'jib' and a 'mainsail' on the one set of battens, like a junk rigged Swing Wing or Aerorig. This would appear as in Figure 8 and may have the following advantages –

1. With the convex luff balancing the convex leech, simple fixed batten parrels and downhaul tension aligned with the straight 'mainsail' luff there should be no need for either luff parrels or Hong Kong parrels.
2. The downhaul tension should control the twist as on a simple balanced lug so it should be possible to use a simple 2-part sheet on the boom.
3. With so much balance it should not be necessary to move the rig fore and aft to balance the boat on and off the wind.
4. The 'mainsail' may require less camber as the 'jib' shape and setting will be the most important to produce windward drive. Also the chord of the 'mainsail' would be reduced compared to a single sail case so there would be significantly less broad seam required achieving the sail camber.
5. The interaction between the two 'sails' may encourage faster flow over the lee side of the 'jib' and encourage enhanced upwash and better drive.

There could also be some disadvantages –

1. The shaping of the broad seam of the 'jib' panels would be critical to the windward performance.
2. Reefing may not be as easy as with a conventional junk as the bottom batten after each reef would have to be tensioned by a downhaul at both luff and leech, however modern single line reefing may help to achieve a good set.

The obvious name for this rig would be the Split Junk, or SJ for short.

As mentioned in the first paragraph, the author is keen to receive criticism of these thoughts in an effort to open a debate and expand the pool of knowledge.

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# Downwind Faster than the Wind - Some Responses

## Yes, one can

In this issue of the Catalyst, delightful as usual, you ask members to say whether they believe in DWFTTW. I do, and my belief is based on a very simple analogy which I tonight confirmed by wrapping sewing thread round a pepper mill.

I found one of those tall pepper grinders which has a smaller diameter at the middle than the top or bottom. This particular one had the same diameter top and bottom, which was convenient. I wrapped thread round the narrow part, and laid the pepper mill on its side with the thread coming away from the lower side, parallel to the ground. When I pulled gently on the thread the mill rolled towards me, winding in the thread, till it touched my fingers and stopped.

Anyone can try the experiment, with any shape like a pepper mill, or and old fashioned thread spool, or a Diablo.

Anyway the analogy is this:

The thread is the wind, passing over the floor.

The narrow circumference of the pepper mill is the wind rotor, pulling in the thread or wind.

The rims of the pepper mill, touching the ground (sea) are the sea propeller, which is dragging against the floor (sea) and driving the narrow part (wind rotor) round to pull in the thread (wind).

I am pulling the thread past the floor, and thus putting energy into the system, so it is not a perpetual motion machine.

To make a floating device do all this would require great efficiency and low friction, but not in principle impossible. So add my name to the supporters of DWFTTW!

*Cheers,*
*'Topher Dawson*
*topher@cd2.com*

## I don't believe it

In reply to Frank Bailey's question I do not believe it is possible to sail directly down wind faster than the true wind speed, my reason for saying this is that the apparent wind reduces as the boat speed increases and the power available will fall to zero at boat speed equals true wind speed and no further acceleration will be possible, in practice reduced power will prevent even approaching a speed equal to wind speed.

I feel that it is also unlikely that tacking down wind will produce a course made good speed of true wind speed (ie.with Wind blowing A to B can high efficiency boat, ice yacht or land yacht travel via C in a time short enough for Distance AB divided by elapsed Time to be equal to or exceed True Wind Speed), although I know from experience this is best way to sail down wind once the skill has been developed to maintain a course that is down wind and not a broad reach (which is great fun but doesn't get you anywhere except by leeway!)

Does any one know where I can see land yacht and ice yacht polar diagrams? I am told that they are always sailed close hauled but I suspect they can sail slowly on most courses, but it is more effective to sail close hauled and fast to complete any triangular course competitively.

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*[Tom Speer/Bob Dill -- Do you have available polar diagrams for land/ice yachts? -- Ed]*

# DWFTTW - A Skiff Analogy

Slieve McGalliard

The article titled 'Downwind faster than the wind' which appeared on page 12 of Catalyst number 10, October 2002, was a print from a communication about a letter on the subject, and taken in isolation does not make sense. The original article went something like the following.

The AYRS meeting on the 7th February 2002 took the form of a discussion on the ability to sail straight down wind faster than the wind. Despite the efforts of John Perry convince the assembly and his explanation using a model of 2 helix of different pitches fixed end to end, the assembly broke up with more unbelievers than believers. Many were talking of perpetual motion, and something for nothing, and with the inefficiencies of the systems being discussed the unbelievers did seem to have a point.

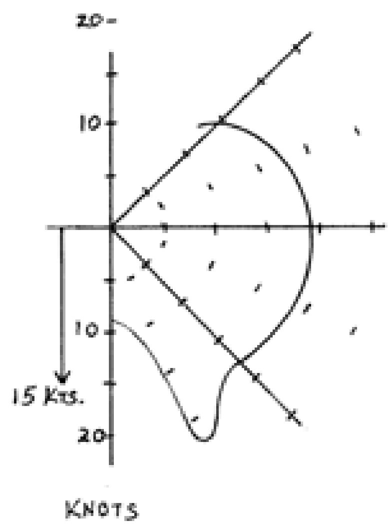


*Fig. 1.*

However - approaching the subject from a different direction may show that is possible to 'sail' straight down wind faster than the wind, and that John's explanation was sound.

Rather than start with a theory, let us start with accepted performance figures. Frank Bethwaite, in his most excellent book entitled 'High Performance Sailing', chapter 24, figure 24.1, shows a polar diagram for an 18 foot skiff. (Fig. 1 is a sketched copy for ease of reference). In the 15 knot case, the skiff can sail at 22 knots at an angle of 153° from the true wind, or 27° to the true down wind direction. This represents a VMG to downwind of 19.6 knots, which is 30% greater than the true wind speed.

In figure 24.2, (sketched as fig. 2), Bethwaite shows the apparent wind vector diagram for this situation as diagram 'h'. This shows that when 'broad reaching' at 22 kts the skiff is actually close reaching at 38° to an apparent wind of 11 knots. The 18 foot skiff can achieve this performance by flying a relatively flat reaching asymmetric spinnaker that trebles the area of the fore and aft rig.

This situation can only occur as the forces of the rig react on the centreboard, and drive it through the water to produce the apparent wind mentioned above. Remove the centreboard and the boat will just blow off down wind at a speed less than the true wind speed.

The question is - can this performance be reproduced while sailing on a dead run? The answer has to be 'Yes', as long as we can compact the motion into rotary motion and provide a 'keel' for the 'rig' to react against and produce the required apparent wind.

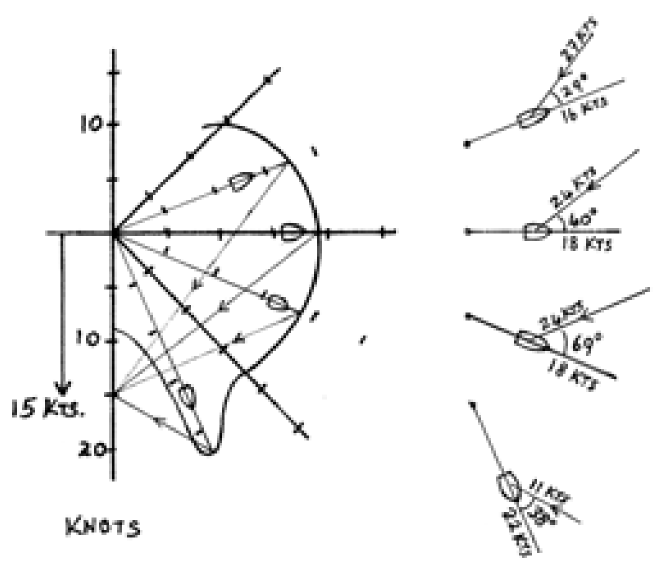


*Fig. 2.*

*Fig. 3.*

The 18 foot skiff is made up of three components, rig, hull and foils, and as long as we can replicate all three then we should have a working model. The following explanation starts with an impractical model to show how it might be made to work, followed with an explanation how it might be modified towards a practical solution.

Consider a planing hull set to run dead downwind, and rigged with a windmill. Instead of normal windmill sails, fit a pair of 18 foot skiff rigs on long arms with the foot of their masts pointing towards the centre of rotation, as illustrated in fig.3. If the sail trim of the rigs could be adjusted then the requirements for the rig of the 18 foot skiff to produce the performance as depicted in the polar diagram are met.

For the skiff to perform it requires the foils in the water to react against. Fitting a pair of centreboards in the form of a propeller in the water, driven by and/ or driving the rotation of the 'sails' of the windmill, and arranging the propeller pitch to be variable from fully positive to fully negative would provide the full range of close hauled to dead run sailing conditions and therefore covering all points of sailing.

By varying the pitch of both the rigs and the propeller the full range of the sailing conditions as depicted in the polar diagrams could be reproduced, including the 130% wind speed downwind run.

To start this impractical model on its journey down wind, the rigs would have to be turned towards the wind to a close hauled angle with the sails trimmed to match and the propeller/ centreboards adjusted accordingly. This would start the windmill rotating, and the vehicle moving. By adjusting the point of sail of the rigs and the foils as illustrated in fig. 2, diagrams e, f, g, and h (and hoisting the spinnakers at the appropriate time) the vessel would accelerate to a down wind speed of some 130% of the wind speed.

The guide on how to convert the above into a practical model is also clearly illustrated in Frank Bethwaite's book, chapter 17, paragraph titled '17.8 Dreams and realities'. Despite the obviously high performance of the 18 foot skiff rig, the aerodynamic efficiency of a glider wing (and even a model glider wing) is of a completely different magnitude! If the 18 foot skiff 'sails' of the impractical windmill model above are replaced by significantly higher efficient model glider wings, and an appropriate twist introduced into the angle of attack of the 'sails' as is normal in a propeller, we should end up with a practical working model. See fig.4.

Effectively the model now becomes a model gyro boat, with the rotor driving or being driven by the propeller. Radio control could be used to steer the boat and vary the pitch of both the airscrew and the water propeller.

Returning to the discussion at the AYRS meeting, John Perry's explanation and model worked on the same principle as the above, but did not advocate variable pitch on both screws, which was probably the reason it was difficult to accept. Most people who try to explain the idea end up with a 'black box' gearbox in the connection between the airscrew and water propeller. Controlling the pitch of both replaces the black box.

It is not a case of 'will it work' as Frank Bethwaite's figures show that it will; but rather the question is: Can anyone make a good enough model to demonstrate the effect?

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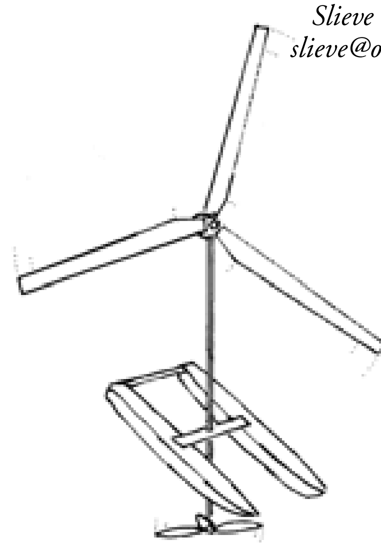


*Fig. 4.*

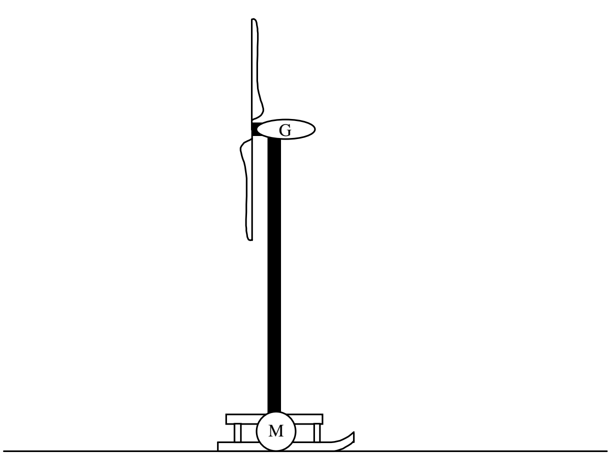
# DOWNWIND FASTER THAN THE WIND?

Mario Rosato

This subject always seems to arise discussions among sailors. It seems to exert some kind of fascination on sailing people and inventors, somehow like the possibility of creating a "*perpetuum mobilis*". There is some literature about "inventions" that should be able to sail downwind faster than the wind "if mechanical losses and/or hull resistance are kept at the minimum". Even rigorous books like Ross Garret's *Physics of Sailing* present somehow confusing "demonstrations" of the theoretical possibility of sailing downwind faster than the wind. In the same chapter Garret presents the results of an experiment conducted in New Zealand by Jim Bates on his ship *Te Waka*: the measured speed was about half the wind speed practically on all courses, quite in contradiction with Garret's "theorem". On AYRS publication 120-I *21st Century Multihulls*, pages 49 to 63 Joe Norwood Jr. explores the subject and finds a theoretical possibility only if certain conditions are met, which Mr. Norwood himself supposes unrealistic. The author has no (scientifically documented) knowledge of any craft that have ever reached this goal. It is then worthy to explore if there is at least any theoretical possibility of achieving such performance.

## 1. The theoretical model

The most frequent invention proposed is some kind of craft carrying a windmill, which extracts energy from the wind and uses it to drive a propeller, which in turn pushes the craft. Let's analyse a very theoretical case, in which a craft with the lowest possible drag and ideal transmissions will be considered, together with the best theoretical windmill. This ideal craft should look more or less like this:

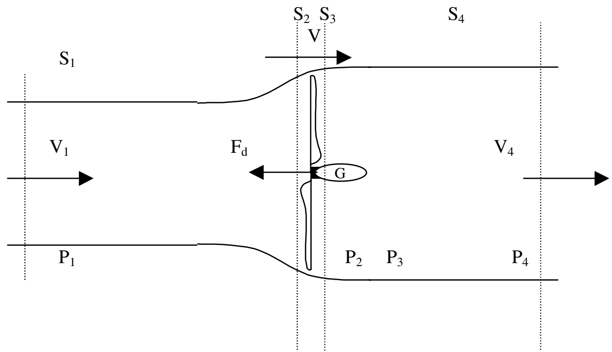



The ideal windmill drives an ideal generator (with no losses), G; which drives an ideal motor, M, which converts all the power received into motion. (Suppose it drives a toothed wheel that perfectly grips on ice, without any slipping).

The skibob running on ice is the craft with the lowest drag possible we can imagine (an eventually construct). Unlike a hull in water, the drag of a skibob on ice is constant, i.e., it is independent of the speed if we don't consider the windage (in this case there's a second drag component, varying with the square of the apparent wind speed). We must now define what an "ideal windmill" is. Such a device is called "Froude's actuator disk" or "Betz's windmill". The German professor Betz was the first to demonstrate with a theorem, what the maximum power is that can be theoretically extracted from the wind. (Some American literature claims the first was not Betz, but a certain Lanchester. *"À tout seigneur, tout honneur*". We'll carry on calling it Betz's Theorem, just because we are used to).

## 2. Betz's Theorem: the equivalent of Carnot's Theorem in Thermodynamics.

We'll explore then which is the maximum power we can draw from wind, in order to define what an ideal windmill is. Such a windmill, or "actuator disk", is a device that produces a pressure drop in a free flowing stream (i.e., it is not placed in a tube), without altering the flow speed through it. Let's clear up this concept with a simple sketch.




Everything in this model is supposed to be ideal. The fluid is incompressible; and it is flowing through section $S_1$ at the speed $V_1$. The sections $S_2 = S_3 = S$ = area of the rotor = $\pi r^2$. The speed through these sections, V, does not vary, and the pressure drop is totally converted into mechanical energy by the "actuator disk", which produces a reaction $F_d$. Another condition is that $P_1 = P_4 = P_{atmospheric}$ if the sections $S_1$ and $S_2$ are "away enough" from the actuator disk in order not to suffer its influence.

Since the fluid is incompressible, the mass passing through each section must be constant (the so called continuity equation):

$$\rho S_1 V_1 = \rho S_2 V = \rho S_3 V = \rho S_4 V_4$$

Applying Bernoulli's equation to both sides of the actuator disk, we obtain:

$$P_1 + ½ \rho V_1^2 = P_2 + ½ \rho V^2$$
$$P_3 + ½ \rho V^2 = P_4 + ½ \rho V_4^2$$

And subtracting both equations from each other:

$$P_1+½\rho V_1^2 - (P_4+½\rho V_4^2) = P_2+½\rho V^2 - (P_3+½\rho V^2)$$

Taking into consideration the above suppositions, we can simplify the equation, so the result will be:

$$½ \rho(V_1^2 - V_4^2) = P_2 - P_3 = \Delta P$$

The thrust $F_d$ produced by the pressure difference is then:

$$F_d = \Delta P.S = ½ \rho S (V_1^2 - V_4^2) \qquad (I)$$

We can also consider that the thrust $F_d$ multiplied for a unit of time must be equal to the variation in the momentum of the fluid mass at both ends of the system (the so called "Newton's impulse function", or "Euler's Theorem". Again, the literature gives different names to the same thing).

$$F_d\, t = m (V_1-V_4)$$
$$F_d = m (V_1-V_4) / t$$

But the quotient *m/t* is the mass flow through the sections, usually called Q (in some literature is also called m), which can be written as:

$$Q = \rho S V.$$

So, replacing it in the expression of $F_d$:

$$F_d = \rho S V (V_1-V_4) \qquad (II)$$

Equating (I) and (II), we obtain:

$$½ \rho\ S (V_1^2 - V_4^2) = \rho S V (V_1 - V_4)$$

Hence:

$$½ (V_1^2 - V_4^2) = ½ (V_1 - V_4)(V_1 + V_4) = V(V_1 - V_4)$$

So: $$(V_1 + V_4)/2 = V \qquad (III)$$

(III) is a very important relationship, which we shall use in the following reasoning:

By the energy conservation principle, the power extracted by the actuator disk must be equal to the variation of kinetic energy of the fluid flow. The variation of the kinetic energy can be written as:

$$P = \Delta E = ½ \rho S V (V_1^2 - V_4^2)$$

Substituting as in (III)

$$P = ½ \rho S((V_1 + V_4)/2)(V_1^2 - V_4^2)$$
$$= ¼ \rho S (V_1 + V_4) (V_1^2 - V_4^2)$$
$$P = ¼ \rho S (V_1^3 - V_1 V_4^2 + V_1^2 V_4 - V_4^3) \qquad (IV)$$

We want to calculate under which conditions P reaches its maximum value. For doing this, we must take the derivative of (IV) considering $V_1$ as a constant and $V_4$ as the variable, and then set the derivative equal to zero. By Weierstraβ's Theorem, solving the resulting equation will give the value of $V_4$ that makes P a maximum (or a minimum, or an inflexion point, which must be checked a second time). So:

$$dP/dV_2 = ¼ \rho S (0 - 2V_1V_4 + V_1^2 - 3 V_4^2) = 0$$

Solving the quadratic equation between brackets leads to two solutions:

$$V_4 = -V_1$$

or $$V_4 = V_1 / 3$$

The first solution has no physical sense, because assuming $V_4$ to be negative means that the actuator disk extracted more energy from the fluid than the fluid itself has. **This would violate the energy conservation principle;** so the only solution possible is the second one. Checking it with Weierstraβ's criterion, we can demonstrate that it is really a maximum (if you do not believe, just replace $V_4$ by a value smaller than $V_1/3$ and see if the derivative gives a positive value. Then replace it by a value bigger than $V_1/3$ and if the derivative gives a negative value, then the point is a maximum).

Replacing $\mathbf{V_4 = V_1/3}$ in (IV), we obtain the maximum power an actuator disk can extract from a fluid stream:

$$P_{max} = {}^{16}/_{27} \cdot ½\rho S V_1^3$$

So, the important conclusions to be drawn from this theorem are:

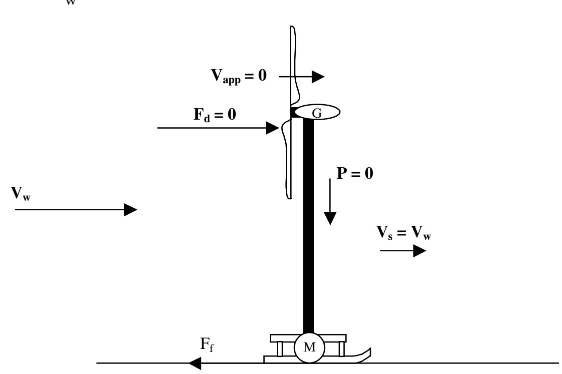
**a) The maximum power an ideal windmill can extract from the wind is equal to 16/27 of the total power contained in the moving air mass.**

**b) To reach this condition, the speed of the air mass downstream the rotor cannot be lower than 1/3 of the wind speed upstream the rotor.**

**c) Betz's theorem is akin to Carnot's theorem. Both suppose ideal machines, which can only extract a fraction of the total energy contained in a given system.**

## 3. The first question: Can the model run at least at the same speed of the wind?

Conclusion (b) above means that, if we consider an ideal rotor to be moving in the stream and all the energy extracted from the fluid being used to accelerate the craft, the maximum speed theoretically possible is any value slightly smaller than $V_w$ (e.g., 0,99 $V_w$). For a given size of rotor, moving faster than the design speed means extracting less power, until no more power can be extracted at all. So, we can conclude that the proposed craft (and no other one in general) can approach as much as we are technologically able, but cannot reach $V_w$ *by its own means.* We could want to cheat and boost it with an external source of energy (a combustion motor, a rocket, whatever you can imagine), and see if it can maintain by its own the same speed of the wind. Under this "cheating hypothesis", let's define which forces would be acting on the skibob once it has reached $V_w$:

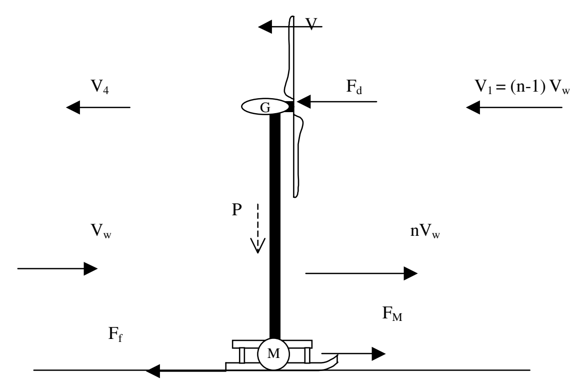



It's evident that if $V_{wind} = V_{skibob}$ then there's no apparent wind through the windmill, hence no power is generated and so there's no force produced by the motor to oppose to the frictional force $F_f$. No reaction force is created by the rotor against the air, so also $F_d = 0$. Hence, the only force acting on the system is the frictional force $F_f$, which tends to slow down the skibob.

**This means that it's impossible to go downwind at the same speed of the wind.** A craft which could eventually be accelerated by external means (for instance, an outboard motor), and then let in free motion once the speed of the wind is reached, will inexorably slow down until an equilibrium condition is obtained at a lower speed. It could proceed at the wind speed only in the ideal case of the frictional force being null, which is obviously unreal.

## 4. The crucial question: Can an ideal craft run downwind faster than the wind?

Suppose we accelerate our ideal skibob by means of an external motor until $V_{skibob} > V_{wind}$, and then the craft is left to its own means. Can it maintain this speed? Let's see which forces act on the system under this supposition.




The skibob is moving at a speed $nV_w$ where $n > 1$. The power generated by the flow through the rotor is P, and the apparent speed of the wind that the rotor actually "sees" is $V_1 = (n-1)\,V$.

The equilibrium of the forces is attained when:

$$F_f + F_d = F_M$$

but, since there are no transmission losses, the power generated by the windmill is the same converted into motion by the motor. So,

$$nV_w * F_M = P$$

and hence:

$$F_M = P / nV_w$$

Since the maximum value of P is given by Betz's formula, we shall replace it in the expression above, thus obtaining:

$$F_M = \frac{16}{27}\cdot\frac{\rho S V_1^{\,3}}{2nV_w} = \frac{16}{27}\cdot\frac{\rho S(n-1)^3 V_w^{\,3}}{2nV_w}$$

$$= \frac{16}{27}\cdot\frac{\rho S(n-1)^3 V_w^{\,2}}{2n}$$

We also know from equation (II) in paragraph 2) that:

$$F_d = \rho\, S\, V\, (V_1 - V_4)$$

and that $V = ½ (V_1+V_4)$

and furthermore, by Betz's theorem, also that $V_4 = V_1 / 3$, hence:

$$F_d = ½\, \rho\, S\, (V_1+V_1/3)(V_1-V_1/3) = ½\, \rho S V_1^2 (^4/_3)(^2/_3)$$

$$= {}^4/_9\, \rho\, S\, V_1^2 = {}^4/_9\, \rho S (n-1)^2 V_w^2$$

We can now calculate the amount of $F_f$ that the system would be able to drag:

$$F_f = F_M - F_d = \frac{16}{27} \cdot \frac{\rho S (n-1)^3 V_w^{\ 2}}{2n} - \frac{4}{9} \cdot \rho S (n-1)^2 V_w^{\ 2}$$

$$= \frac{4}{9} \cdot \rho S (n-1)^2 V_w^{\ 2} \left( \frac{4}{3} \cdot \frac{(n-1)}{2n} - 1 \right)$$

$$F_f = \frac{4}{9} \cdot \rho S (n-1)^2 V_w^{\ 2} \left( \frac{2(n-1)}{3n} - 1 \right)$$

This is a very interesting formula from which we can draw the following conclusions:

a) The craft can't move at the same speed of the wind (n=1), because that would require that $F_f$ is null. This is in full agreement with the conclusions drawn in paragraph (3).

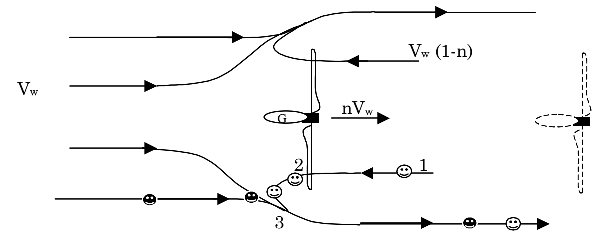
b) To move downwind faster than the wind means that n>1. But under this condition the expression between brackets (**2(n-1)/3n – 1**) will always give a negative value (it can be positive only if n<-4). A negative $F_f$ means having an external energy source acting on the system (since $F_f > 0$ means energy dissipation, the contrary must mean an energy injection). **In other words, the craft cannot run downwind faster than the wind unless there's something more than the wind itself giving power to it.**

## 5. Discussion about some arguments to cheat Betz´s Theorem

Somebody may argue that the reasoning presented in paragraph (4) is not true because $V_4$ should have the same value and sense of $V_w$, hence Betz's formula would not be applicable to this case. This is a misleading argument for the following reasons:

Let's suppose again our ideal skibob running downwind at a speed $V_1 = n\, V_w$, with n>1.

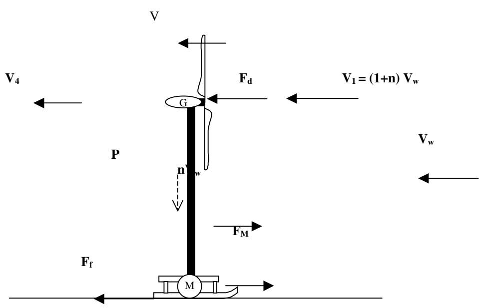
It's possible to demonstrate that the air streamlines through and around the actuator disk would look more or less like this:




To understand the sketch, just imagine that the smileys are particles of the fluid. The rotor is travelling with speed $nV_w$ to the right, so the white particle in position 1, which was travelling to right at the speed $V_w$ actually "sees" the rotor approaching with speed $V_w$ (1-n). From the point of view of the particle, it is ***as if*** it was moving towards a static rotor with speed $V_1 = V_w(1-n)$. One past the rotor (position 2) the particle has given some kinetic energy to the same and has slowed down its speed. If there were no other influences, it would decelerate until reaching 1/3 of its original speed and then continue with uniform movement. Please, note that the fluid stream tends to expand while decelerating, so our particle would have two movement components, one in the sense of the flow and the other perpendicular to it and towards outside. Since the main stream is moving in the opposite direction, the collisions of the white particle with the black particles coming from left will further slow it down until all its energy will have been completely dissipated and its speed will be null (position 3). Since the mass of fluid coming from left is theoretically infinite, it will continue to give energy to our white particle until it will be accelerated in the opposite direction, reaching again the mean speed of the fluid $V_w$ (position 4). Please note that in the meanwhile the actuator disk has moved to right to the position marked with dotted lines, so the white particle won't pass through it a second time. It should be clear now why Betz's theorem cannot be "cheated" by assuming $V_4 = -V_w$. The particles passing through the actuator disk can only give a fraction of the energy they have, and then dissipate the rest against the mainstream, which in turn has no direct influence on the actuator disk. If in point 3 the speed of the white particle is null, it is not because it has given all its initial kinetic energy to the windmill, but just because it has dissipated it against the black particles coming from left.

## 6. Corollary: Is it possible to run windward faster than the wind?

We can make the same reasoning of point 4), but changing accordingly the senses of the vectors. We shall not repeat all the reasoning, but just the corrected formulas: (1+n) instead of (1-n) where corresponding. Please, refer to the following sketch.




$F_d = ½\ \rho\ S\ (V_1+V_1/3)(V_1-V_1/3) = ½\rho S V_1^2(4/3)(2/3) = {}^4/_9\ \rho S V_1^2 = {}^4/_9\ \rho S(n+1)^2 V_w^2$

$$F_M = \frac{16}{27}\cdot\frac{\rho S V_1^3}{2nV_w} = \frac{16}{27}\cdot\frac{\rho S(n+1)^3 V_w^3}{2nV_w}$$

$$= \frac{16}{27}\cdot\frac{\rho S(n+1)^3 V_w^2}{2n}$$

So the maximum friction force the system can handle will be:

$$F_f = F_M - F_d = \frac{16}{27}\cdot\frac{\rho S(n+1)^3 V_w^2}{2n} - \frac{4}{9}\cdot\frac{\rho S(n+1)^2 V_w^2}{}$$

$$= \frac{4}{9}\cdot\frac{\rho S(n+1)^2 V_w^2}{}\left(\frac{4}{3}\cdot\frac{(n+1)}{2n} - 1\right)$$

An interesting result! The expression within brackets gives positive values for n<2. It seems that at least running at a speed $V_w < V < 2V_w$ towards the wind would be possible. It would really be exciting but, unfortunately, it may not be possible: in the ideal model that we have considered till now, the air makes no resistance to the movement of the skibob. If we correct the model according to a more real situation, we shall find that:

$$F_f = F_M - F_d - F_{air}$$

$$= \frac{16}{27}\cdot\frac{\rho S(n+1)^3 V_w^2}{2n} - \frac{4}{9}\cdot\frac{\rho S(n+1)^2 V_w^2}{}$$

$$-- \frac{1}{2}\cdot\frac{\rho S_{craft} C_d (n+1)^2 V_w^2}{}$$

Where $S_{craft}$ is the overall transversal section and $C_d$ is the overall drag coefficient.

Then:

$F_f = {}^4/_9\ \rho S(n+1)^2 V_w^2\ ({}^4/_3(n+1)/2n–1)$-½ ρ $S_{craft} C_d (n+1)^2 V_w^2$

$F_f$ =½ $\rho V_w^2\ (n+1)^2\ ({}^8/_9 S({}^4/_3(n+1)/2n–1) – S_{craft} C_d)$

Please, note that for $F_f$ having a finite value, the term between brackets must be greater than zero. Then:

$${}^8/_9\ S\ ({}^4/_3(n+1)/2n – 1) – S_{craft} C_d > 0$$

$${}^8/_9\ S\ ({}^4/_3(n+1)/2n – 1) > S_{craft} C_d$$

$${}^2/_3\ (n+1)/n – {}^1/_8 > (9\ S_{craft} C_d)\ /S$$

Since the term on the right side of the inequality must be positive, the variable n will have physical sense only if:

$$2/3\ (n+1)/n – 1 > 0$$

and solving it (homework for the reader!) we obtain: n < 2 as in the ideal case.

A very interesting result indeed! This means that, **theoretically at least, our ideal craft can go to *windward* faster than the wind (but no faster than twice the wind speed).**

## 7. Designing a skibob that can go to windward with n= 1,9

Just as an exercise, let's attempt to design such a craft, always considering an ideal windmill, transmission and motor.

Let the design parameters be the following:

W = total weight of the craft = 300 kg @ 3000 N

Cd = total drag coefficient = 0,35 (a well streamlined skibob)

ϕ = friction coefficient of steel skates on ice (the lowest practical value) = 0,014

$V_w$ = 10 m/s (a strong breeze)

$S_{craft} = 2\ m^2$ (the skibob and the windmill's pole together)

$F_f$ = Wϕ = 3000 N * 0,014 = 42 N (really a small drag!)

$F_f$ =½ $\rho V_w^2.(n+1)^2.(8/9S(4/3(n+1)/2n))–1)–S_{craft} C_d)$

42 =½ 1,45 * $10^2$ $(1,9+1)^2$ ( 8/9 S ( 2/3 (1,9+1)/ 1,9 – 1) – 2* 0,35)

42 = 609,725 (0,0156 S – 0,7)

0,068883 = 0,0156 S – 0,7

S = 49,28 $m^2$ – which means a rotor of 7,92 m diameter.

## 8. Final comments

Although a "windmill skibob" with the aforeseen features is in principle feasible, there's no doubt it would constitute a challenge for any engineer, and also would require a generous sponsor. The Author finds unlikely that a boat based on the same principles could be constructed and yield relevant performances, especially because of the much higher resistance of hulls in water and the intrinsically limited efficiency of the propeller. A propeller is limited by Betz's theorem; hence, the maximum power effectively used to drive the boat would be a fraction – ideally 16/27 and practically much less than that - of the power produced by the windmill.

Other configurations could be proposed, but it's not possible to analyse all of them here. Just to answer to Mr. Perry's kind email, which inspired the Author to write these lines, we'll shortly analyse two of them. The Author finds very ingenious the solution proposed by Mr. Peter Sharp (see Catalyst No 3 page 26, or Mr. Perry's site *http://www.btinternet.com/~sail/dwfttw01.htm*). It consists of two boats, one remaining practically still and transmitting the power produced by a windmill through a high voltage cable to a second one, moving downwind faster than the wind. Though it's the Author's opinion that the same is not practical, we must say that the idea can theoretically work. In fact, the windmill mounted on the boat that remains practically stationary would be extracting the maximum power it can. On the other side of the cable, the boat running faster than the wind should be receiving energy from an external source (a source not mounted on the boat itself), in total agreement with the conclusions of point (4), so there would be no violation of Betz's law. What's difficult to accept is the concept that two boats, one moving and the other practically still, can be considered as one single craft just because there's a cable joining them.

The second page of John Perry's site (*http://www.btinternet.com/~sail/dwfttw02.htm*) proposes an analogy between propellers and metal screws. Following his reasoning, if the windmill and the water propeller had different pitch, it could be possible to go downwind faster than wind. The mechanical analogy is ingenious but misleading. The "air nut" and the screw move indeed with different speeds relative to the "water nut", just because the work done to make the "air nut" move relative to the screw plus the work done by the screw to move relative to the "water nut" equals the work done to move both nuts relative to each other. In other words, the efficiency of the energy conversion in the proposed system is (theoretically) 100%, while in the propulsion case getting energy from the wind (and transferring it to a flow of water) is subject to Betz's maximum limit 16/27. It's not a problem of pitch ratio, but of energy balance.

As far as Mr. Andrew Bauer's experiments are concerned, the Author has no numeric data about them, but from Mr. Perry's description, it seems that Bauer's craft was somehow like the windmill skibob we used in our reasoning above. One should be cautious before accepting figures as true. Is it sure that the tests were performed on perfectly even ground? (A descending slope is an external energy source!). What was the precision of the measurement instruments used? Were there values derived by calculation or direct measurement? (See the Author's comments on Catalyst Oct. 2002 about the propagation of errors in formulas).

## 9. CONCLUSIONS

Now it is clear that running downwind at the same speed, or faster than the wind is theoretically impossible - even in ideal conditions! Going to windward faster than the wind is theoretically possible, but with a top speed equal to twice the wind speed. In any case, due to Betz's limits in the energy conversion, the size of the windmill compared to the craft should be enormous if some relevant performance of the proposed model is desired. This means engineering problems that are difficult – and expensive - to solve.

Something must be said in favour of windmill boats: they are potentially very safe and sailing them would probably be quite easy. The Author has never sailed one, but intends to develop and construct a model in the future. It seems that such boats should behave more or less like motorboats, but with ecological advantages. The reason for this is that the performance is limited by the size of the windmill (remember that the power available is directly proportional to the rotor's diameter). Hence, the power available is more or less the same, independently of the course to wind (like with a motorboat). Reefing in case of strong breezes should be very easy (just braking the rotor, or folding it, or changing the blade's pitch). They should be then quite safe and suitable for family cruising. On the other side, their speed potential will be inferior to conventional sail yachts, except perhaps on going to windward.

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*Barcelona, Spain*

This is a free listing of events organised by AYRS and others. Please send details of events for possible inclusion by post to Catalyst, BCM AYRS, London WC1N 3XX, UK, or email to **Catalyst@fishwick.demon.co.uk**

## January 2003

**2nd - 12th London International Boat Show**
Earls Court Exhibition Hall. Those who can give a day or two, from 15th December onwards, to help build/staff the AYRS stand (**reward - free entry**!) should contact Sheila Fishwick
tel: +44 (1727) 862 268; email: ayrs@fishwick.demon.co.uk

**11th AYRS Annual General Meeting**
19.30 for 20.00hrs at the London Corinthian Sailing Club, Upper Mall, London W6. Contact: AYRS Secretary, BCM AYRS, London WC1N 3XX; tel: +44 (1727) 862 268; email: ayrs@fishwick.demon.co.uk

## February

**5th AYRS London meeting** on ***John Hogg competition***
19.30 for 20.00hrs at the London Corinthian Sailing Club, Upper Mall, London W6. Contact: AYRS Secretary, BCM AYRS, London WC1N 3XX; tel: +44 (1727) 862 268; email: ayrs@fishwick.demon.co.uk

**23rd High Speed Sailing Projects**
All day meeting at Thorpe Village Hall (between Chertsey and Staines, junctions 11 and 13 M25). For map etc contact AYRS at the London Boat Show or Fred Ball, 1 Whitehall Farm Lane, Virginia Water, Surrey. GU25 4DA; tel: 01344 843690 email: fcb@globalnet.co.uk

## March

**5th AYRS London meeting** on ***Members projects*** 19.30 for 20.00hrs at the London Corinthian Sailing Club, Upper Mall, London W6. Contact: AYRS Secretary, BCM AYRS, London WC1N 3XX, UK; tel: +44 (1727) 862 268; email: ayrs@fishwick.demon.co.uk

## April

**2nd AYRS London meeting** on ***Building Boats for Experiments***
19.30 for 20.00hrs at the London Corinthian Sailing Club, Upper Mall, London W6. Contact: AYRS Secretary, BCM AYRS, London WC1N 3XX; tel: +44 (1727) 862 268; email: ayrs@fishwick.demon.co.uk

## May

**12th - 16th Sailing Meeting**
***Mainly for speedsailing boats, but all are welcome,*** Castle Cove Sailing Club, Weymouth, UK. Contact: Bob Downhill;
tel: +44 (1323) 644 879; email: icaruswsr@tiscali.co.uk

## October

**4th - 10th Weymouth Speedweek**
Weymouth & Portland Sailing Academy, Portland, UK, Contact: Nick Povey, tel: +44 (7713) 401 292; email: nick@speedsailing.com

## AYRS London Meetings

Please note that from now on, the AYRS London meetings will be on the first WEDNESDAY of every winter month, not the first Tuesday. Still at the London Corinthian Sailing Club though.

# Catalyst — *a person or thing acting as a stimulus in bringing about or hastening a result*

## On the Horizon . . .

High speed sailing craft - Giles Whittaker
Autonomous Winsailed catamaran - Gabriel Elkaim
Paddle wheels - Ambus Janko
Mill-Prop Paradigm - Peter Sharp
Flying Proa - Roberto Rampinelli
More sources and resources: reviews, publications and Internet sites

**Amateur Yacht Research Society**
BCM AYRS, London WC1N 3XX, UK

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