Catalyst

Journal of the Amateur Yacht Research Society

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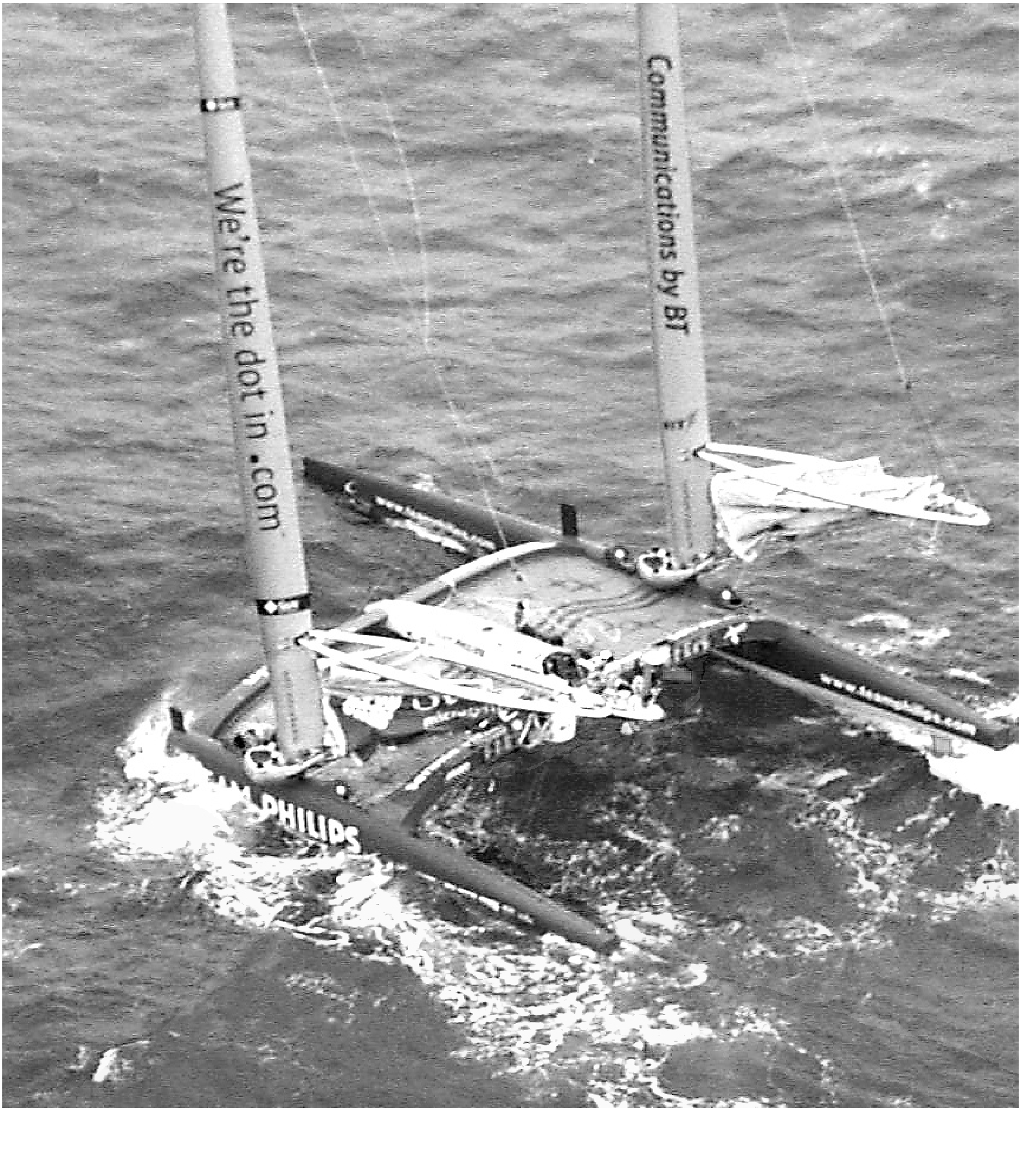

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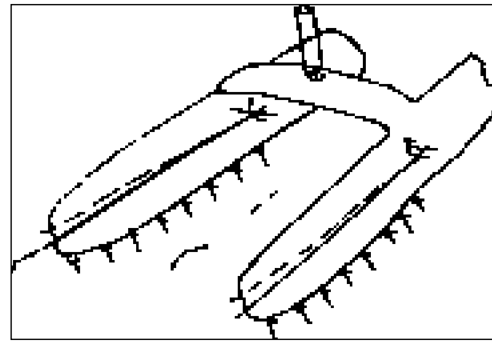

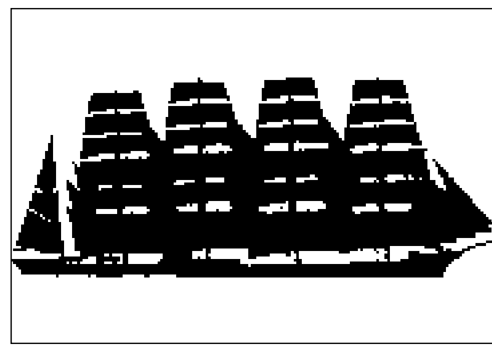

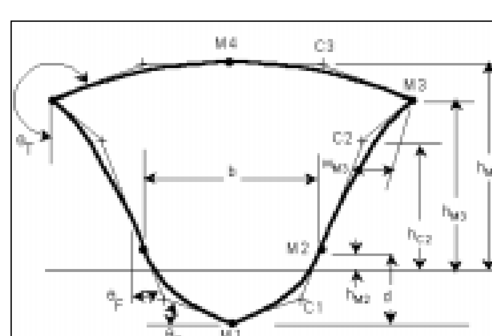

On the Cover –

Team Philips *sails back to port after losing the front half of her port hull.*

Photo: Rick Tomlinson

Catalyst

Journal of the
Amateur Yacht Research Society

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Sir Reginald Bennett VRD,

22 July 1911 – 19 December 2000, past-Chairman of AYRS

Sir Reginald Bennett was best known to the general public as a British Member of Parliament, and the man who as Chairman of its Catering Sub-Committee filled its cellars with fine wines, but to the yachting world he is better known as firstly Chairman of AYRS and then of the WSSRC.

He was born in July of 1911, in Sheffield, England, the son of a civil servant. He won a scholarship to Winchester School, where he started the school sailing club, and another to Oxford University where he read physiology. He then continued his studies in London first in medicine then specialising in psychiatry.

He had always had a love of yachting. At Oxford, he sailed for the University from 1931 to 1934, and in 1934-5 was helmsman and navigator on the J-Class Shamrock V, racing against the Americans for Sir Richard Fairey. In 1936, he was reserve for the British Olympic yachting team at Keil, and later raced in the 12 Metre yacht Evaine. He was founder of the Imperial Poona Yacht Club, an institution which despite its name is peculiarly British, devoted to the lighter and enjoyable things of life. For example, each year it challenges the Oxford University Sailing Club to a backwards-sailing race on the River Thames!

He learned to fly before the war, and gained his wings with the British Fleet Air Arm in 1941, serving as a flying medical officer with the rank of Surgeon Lieutenant-Commander (RNVR). He was torpedoed twice, and awarded the Voluntary Reserve Decoration in 1944.

He was elected Member of Parliament for Gosport & Fareham in 1950, remained so until his retirement in 1979. A master of fine wines, he won a number of wine-tasting competitions, and claimed after his retirement to have made the best use of the Parliament cellars since Guy Fawkes filled then with gunpowder in an attempt to blow up the building (and the members) in 1605!

Reggie Bennett became Chairman of the AYRS in 1972, succeeding Sir Peregrine Henniker-Heaton, and served until 1990. During his time he built up a strong support for the Society. He was a yachting friend of Prince Philip, Duke of Edinburgh, and persuaded him to become our President. In 1980, he succeeded Beecher Moore as Chairman of the RYA Speed Sailing Committee, and when that body was transformed into the World Speed Sailing records Committee, became its first Chairman, continuing until shortly before his death. Under his patient leadership, the WSSRC has become universally recognised as the authoritative body for the supervision and ratification of records under sail.

He is survived by his wife, four children and grandchildren, to whom AYRS extends sincere condolences.

John Hogg, 19th March 1915 - 24th July 2000

The AYRS's longstanding member John Hogg died on 24th July 2000 at the age of 85.

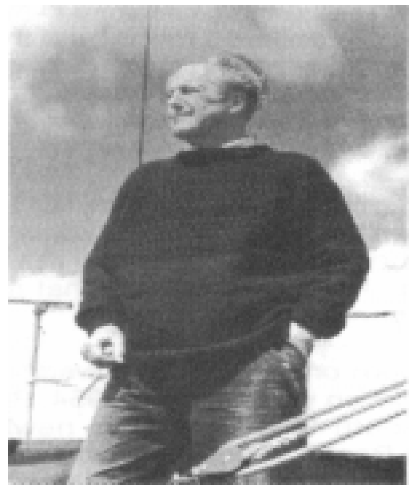
John was born soon after the start of the Great War on March 19th 1915 in the seaside village of Sketty, near Swansea, close to the home of his mother's talented Cavill family.

After the Armistice his father returned to the iron and steel industry and the family moved north.Although the family suffered much from the effects of the Depression on employment in steel making, John received an excellent education at the Manchester Grammar School. This led him into his lifetime management career with the Gas Industry as a chartered engineer.

In the early 1950s, John had moved South to manage the newly nationalised Southern Gas Board in Bournemouth and, of course, to mess about in boats of every description. By this time he was already a radio control pioneer, developing most of the radio and electromechanical systems for a succession of model yachts which he raced successfully in Poole.

This led inevitably to his work on yacht research, testing scale models of America's Cup challengers Sceptre, and Kurrewa and designing and building new ways of measuring sailing performance at full size. As well as providing endless fun on other people's boats, he found this a perfect outlet for his extraordinary inventive skills.

Soon he was creating microelectronic forerunners of today's instruments for measuring wind and water speed, aerofoil shape, boat speed to windward (Vmg), and countless other gadgets which his embarrassed children would be expected to test on roads and various other public places.



Working with good friends [George Chapman and others], his papers on performance measurement provided an important practical contribution to the creation of the Amateur Yacht Research Society and its influence on fast yacht design.

In 1960, when his job moved to Southampton, the family moved to Curdridge. It was here that John and Ena settled happily in the year leading up to his retirement. Only then was he persuaded to buy an extremely small yacht of his own. Moored on the Hamble, the 'Emily Rose' was frequently trailed to St Mawes for their annual holiday and on it he enjoyed many happy summers with his grand children, Derek Mallinson and other Curdridge friends.

In 1970, sailing had started to become an industry, and John's son Rodney was able to apply some of this home background when he joined the small business that has developed into rope-holding equipment specialists, Spinlock Ltd. Cowes.

John was the first to acknowledge that his rich and varied life was only made possible by Ena's endless patience and devotion. As wife, mother, crew, cook, housekeeper, secretary, she was always the supporting audience that he needed. So when the time came, and illness forced her to slow down, he relished the opportunity to care for her for as long as he was able.

It was from the strength of their life together in Curdridge that John so enjoyed being able to combine his fascination with researching, measuring and making things with his abiding love for the village and its people.

I met him in 1947 shortly after he had helped form the Radio Controlled Models Society. Those were the days of one-valve receivers working a sensitive relay which in turn controlled electro-mechanical devices, in which he employed much ingenuity. He was on to transistors as soon as they came on the market, and led their use.

Equally, and for the AYRS more important, he was a leader in sailing boat performance measurement, using pocket-money budgets and largely home-made equipment. Looking back it is remarkable that he was involved with America's Cup challengers, but times have changed ! Even when 'affordable' yacht performance instruments came on the market in the late 1950s, the cost of a full outfit equalled what he (or I) was prepared to spend on the boat. This is still largely true, but then it is difficult to compete financially with sponsored professionals. Only in very recent years has the price of dinghy-scale equipment started to come down.

His writings in AYRS publications rank with those of, for example, Edmond Bruce and Harry Morss, and are a lasting memorial.

He was a good friend who will be sorely missed.

— *G.C.Chapman*

Winds of Change: A Rally for innovative water craft

We had great weather for our first "Winds of Change" Rally which took place on August 18th–20th, at the Royal Harwich Yacht Club, on the estuary of the Ricver Orwell in Essex, E. England.

We had a good uptake in people attending, in fact 31of us partook of the dinner and the social evening on Saturday evening where innovators discussed and showed videos of their ideas, some of these still being models. Speakers included Simon Sanderson who will be making an attempt at breaking the World speed record in "Bootiful", a 50' catamaran with innovative steering currently awaiting favourable wind conditions.

There was Chris Evans from Germany discussing his foiled 20' Trimaran and Peter Rhodes-Dimmer discussing his current Royal Canoe Club Class B Sailing Canoe project, a 17' hull powered by a Boatek wing asymmetric foil. Kim Fisher showed us a model of a concept he has in mind for a water-borne sailing vessel using land yacht principles with flotation wheels instead of hulls. Bob Downhill stood up and said a few words. He had been invited and had kindly agreed to attend the event and to be responsible together with Norman Phillips to run the timing for the speed course using his own sophisticated equipment including laser tape measurement.

Among the models demonstrated on the water were:

A sophisticated Hapa lateral resister/stabiliser by John Perry

An wind-controlled symmetric foil sail on a 6' radio-controlled model showing its paces and control worked convincingly by Peter Worsley.

An 18" windmill powered model proved its ability to go directly into the wind (believed by some to be a breach of the Laws of Thermodynamics) but proved in fact that this certainly is not bogus. To go against the wind using windmill power is possible! again by Peter Worsley.

Other models not actually on the water were scattered about the lawns in front of the club and being thoroughly discussed by the designers.

Among the man-carrying boats not on the speed run was Torix Bennett who unfortunately could only be with us for a half day on Friday with his tri-scaph "*Mini-Sea Spider*" but he quickly launched and demonstrated its impressive ability.

A 10' pram dinghy with an old version of the Boatek asymmetric foil sail was available for anyone to have a go at and had a good take up of enthusiastic volunteers.

Winds in general varied between 19 and 7 on Saturday and 15 and 6 on Sunday. Top speeds measured over a 500m course were:

Saturday

Philip Middleton with "*Triton Chariot*", a 20' foiled trimaran achieved 13.32 knots, wind speed ratio 0.86

Patrick Mayne with "*Speedbird*" a 21' long Bruce foil stabilised monohull achieved 11.09 knots, wind speed ratio 1.39.

Simon Fishwick with his 16' open sailing canoe achieved 4.70 knots, wind speed ratio 0.38.

Sunday

Danny Mann/Philip Middleton took over "*Triton Chariot*" achieving 17.39 knots, wind speed ratio 1.24.

A *National 12*, (helmsman's name not known) achieved 7.77 knots, wind speed ratio 0.60.

Chris Evans with "*Trixi*", an aerorig trimaran achieved 7.19 knots, wind speed ratio 0.48 (before he broke his mast)

Slade Penoyre with an early *Catapult* inflatable catamaran achieved 7.18 knots, wind speed ratio 0.80.

John Perry towing his hapa

Triton's Chariot

Simon Fishwick's canoe crept up to 4.97 knots, wind speed ratio 0.41.

Many thanks to the Commodore, the sailing committee and members of the Royal Harwich Yacht Club for not only allowing but also actively helping to make this a successful event. Special mention must go to Herbert the driver of the committee boat which was used for stake boat No 1, and Terry Corner, vice commodore, skipper of his own 30' Freedom rig yacht being stake boat No 2.

Lots of others to thank! Chris Evans, co-sponsor of the event donated champagne and wine for the individual events. Linda & Denis Alan, with their motor boat and C & D Rowe, with their 14' hydrofoil stabilised craft, standing by as safety boats, Steven Fryer who brought his motor cat fishing boat around from Felixstowe Ferry to act as support boat on the course. Sheila Fishwick who split her time between manning the shore based headquarters and spending time on the stake boats. In fact all those who made the event go with a swing.

— Bob Quinton

Monohull 24 hour record now 430.7 miles!

Dominique Wavre, skipper of 18m (60ft)Vendée Globe entry *Union Bancaire Privée*, has claimed the records for the maximum distance sailed by a singlehanded monohull in 24 hours with a distance of 430.7 nautical miles between December 8 at 17:00 UTC and 9 December at 17:00 UTC an average of 17.95 knots.

Sailing at speeds of up to 30 knots at times, the Swiss registered *Union Bancaire Privée* set the record between 45° 45' 21S, 11° 22'E and 45°22S, 21° 37E on its way round the tip of Africa into the Southern Ocean.

With the arrival of this good news, the delighted skipper commented: " It is super to baptize my entry in the Indian Ocean with this record. I was already a few years ago holder of the record as a crew with Intrum Justicia during the Whitbread with 427 miles; but that was set approximately 1000 miles more to the east from here, and we were 12 on board under spinnaker!

It is a little mad to be going faster with a shorter boat and singlehanded! These boats are fabulous and especially *Union Bancaire Privée* which is a true 'wind-rocket'. It is stressful, the boat vibrates a lot, like a sailboard and it all becomes difficult on board. One really is very shaken and I have even got a little fed up! But I am super content with the way we're going."

With bursts of speed to 32 knots, the skipper thought well of being close to dethroning Yves Parlier of his record established last December (420,06 traversed miles). Marc Thiercelin, his predecessor, had two years old earlier made 396,5 miles during one of the stages of Around Alone.

At the time of writing, *UBP* and the rest of the Vendée Globe fleet are crossing the Southern Indian Ocean towards the south of Australia. "According to the forecast weather, the situation which awaits us in the south of Australia is delicate. There is a depression which discourages us from leaving the course for Cape Leeuwin but an enormous anticyclonic ridge which bars the pathunder Australia. The weather is not too cold, they are quite lenient conditions for the latitude 50s."

— Information from WSSRC and Wavre's website - www.dominiquewavre.com - Translation: S Fishwick

5 knots or bust - the Editor at Winds of Change!

Your Letters

A Rope Experiment

I'm all for simplicity, but suspect that I'm not the only reader who finds Frank's report *[Catalyst 2, p52]* just a bit too ingenuous. Surely he's used "Young's Modulus" where he should be speaking of "spring rate" - and the distinction is not trivial!

But nonetheless, I do agree that rope manufactureres are remarkably coy about giving proper engineering specifications for their products, and that textbook practice has failed to keep up with the arrival of MMFR (man-made-fibre rope). For instance, in an article in an AYRS publication a few years back, I argued that in many circumstances an anchor warp of MMFR offers more safety for a given mass than does the all-chain warp commonly employed. On the other hand, few sailing books tell us, for instance, that a reef knot in conventional 3-strand man-made fibre rope is more than commonly useless - in fact downright dangerous. Why do the authors of such books leave us to find out the hard way?

And more generally, I feel Frank's letter should encourage us to put more emphasis on "sailing safely" and less on "sailing fast". The latter may be more glamourous, but I suspect more sailors lose their lives through mis-use of ropes and bad seamanship generally than through a misunderstanding of fluid mechanics. Further, as Frank has shown, you don't need a lot of expensive kit to do the research.

Mike Bedwell
michael_bedwell@hotmail.com

Determining Maximum Boat Speeds in Radiosailing:

The question of what R/C sailboat is fastest, has been hotly debated in the past and has been a perennial focus of spirited debate ever since two or more model yachts hit the water. The following is an example that will require the cooperation of anyone that has a constructive idea or ideas on how to improve upon this draft. Any and all of your creative experiential inputs will be most appreciated.

In order for 'order to be created from a potentially chaotic' set of rules, it has been decided to categorize all of the recognized divisions in Radiosailing into three major Classes.

Class 1: All recognized One-Design Classes in the AMYA or any National Radiosailing Authority recognized by ISAF-RSD, regardless of LOA. This is inclusive to multihull; multimasts and all boats will compete only against other boats in its specific class. As a result of the theoretical fact that "all one-design boats are created equal", the skipper will be the holder of record in the Note of Record for that particular One-Design Class of yacht.

Class 2: All recognized Developmental Classes in the AMYA or any National Radiosailing Authority Recognized by ISAF-RSD regardless of LOA. This is inclusive to multihull; multimasts and all boats will compete only against other boats in its specific class. Skipper, design type, manufacturer, and sail / rig designer, year of manufacture and any other detailed pertinent information should be included in the Note of Record.

Class 3: Unlimited Experimental Class: this will be broken up into 2 major sub-divisions. Class 3/A will have monohull yachts. Class 3/B will have multihull yachts. Both of these in turn will be sub-divided into three categories based on LOA; LOA/O over 1.5 Meters; LOA/M medial between 1.1 but not greater than 1.5 meters; LOA/U 1 meter and under but not less then .70 meters. Sail area and numbers of masts will not factor into the unlimited experimental class. As the intention of this class is to go for all-out speed regardless of hull forms and rigging types. But as per Class 2, Skipper, design type, manufacturer, and sail / rig designer, year of manufacture and any other detailed pertinent information should be included in the Note of Record.

An example of a Class 3/B LOA/O boat will be of a multihull yacht that is 1.9 meters LOA.

Rules for "cross-divisional" competition will need to be established in order for a spirit of fairness to be at the forefront. It is recommended that any cross-divisional competitions be kept unofficial in order to reduce redundancy. Redundancy in this context is used as a means for clarification; as each division will already have had it's own individually set records with which to have to compete against.

Course Standard Measurements will be in the metric unit of measurement with the English Standard of measurement in parentisies. The length of the Course will be of two types 2 Long and 1 Short. The 2 Long Courses will measure either 25 or 50 Meters (whichever is practical) with the Short Course measuring 10 Meters. An exception to this will be in the special event that a Set Long Distance Course is called for. New Zealand 's Wellington Model Yacht Club's Project "X" from the South Island to North

Island or from the Shaker Village Sailing Clubs swimming buoy and across Lake Masscoma to the Dartmouth Sailing Facility's outer mooring fields buoy and back, a distance of approximately 3 kilometers (1.8 miles). Or any permanently set distance of approximately 250 meters plus. A permanently set course of between 101 to 249 meters will be considered a Medium Long Distance Course. All speed attempts will be of the "Flying-Start" type. As some yachts are faster going at a particular point of sail then others, the point of sail and course configuration will be set to met the unique requirements of that particular yacht. A note determining the yachts' point of sail should be included. For practical reasons this latter course should be applied using the Short Course or the Medium 25-Meter Course. However, a long distance broad-reach might serve most multimasted / multihull sailing rigs best.

Please, note that this last statement is NOT to be interpreted as an inference for advice, but that as of an example to help clarify the points previously stated.

Verification Procedures will be determined by a committee of not less then 4 current members in good standing with the relevant National Sailing Authority and should have no less then 2 neutral committee members and 2 or more but not more then 7 members of the record attempting yacht club(s). The sanctioning of these events will be done as for any ACCR or any other National or International event' protocols.

Indoors Record Attempts: It is recommended that the use of high-velocity commercial grade fans be used for indoors record attempts. A windmeter measuring the wind speeds in meters per second from 1 meter from the center of each fan used and at the start, midpoint and finish lines be recorded. This will allow for accurate assessments of the conditions used for each attempt.

Outdoor Record Attempts: The variability of any outdoor attempts presents a number of challenges, if wave action, sea state, wind shifts etceteras are counted in, an accurate figure for each run will/should have a constantly variable out-come. In this event the highest speed attained, will be the officially recorded speed for the yacht.

Materials Needed for an official recording: A Radar Gun (two if possible), windmeter(s) to measure wind speeds from the center of the fans at 1 meter, start, mid and finish lines. Stop watches/ chronometers or any other precision timepieces (regular watches are not recommended) time to be recorded to the 1,000 of a second. Any other time / distance precision instrumentation that you can suggest, will be considered for inclusion into this section.

Information on all records and photographs should be forwarded to the relevant Class Secretaries, the Presidents of the National Radiosailing Authorities, ISAF-RSD Officers, the Open Class Secretary of the AMYA and will be kept in the files. Any information will be freely given upon request and an answer returned via e-mail or if by snail mail the request must, please, be accompanied by a stamped self-addressed envelope.

The premise of this endeavor is to keep accurate records on the evolution of our sport of Radiosailing and not as a means of establishing "bragging rights" over one-another' classes. With your cooperation, we will have the opportunity to set the standards for the following generations of skippers, designers, manufacturers and constructors to build upon.

I hope that some of you will forgive me, if in sending you some e-mail messages or letters in request of your counsel that it won't be misconstrued as being intrusive on my part. It's just that I'll occasionally need to "pick-the-brains" of those of you whose advice I've come to trust! A committee of Class Secretaries, AMYA Officers, ISAF-RSD Officers, and as varied a group of individual Radiosailing enthusiasts, as possible will be assembled. Although, our world is getting "smaller", the geographic distances remain the same, so all correspondences will be handled either via e-mail or 'snail-mail'!

A form detailing the Note of Record is presently in the works and will be submitted for your critique in the near future.

Thank you all in advance. Peace and take care of yourselves.

Jose' Torres Jr.
Open Class Secretary
AMYA
torfam@valley.net

The AYRS John Hogg Memorial Prize

The Amateur Yacht Research Society announces the establishment of a Prize to be awarded in memory of John Hogg, the distinguished yachting researcher and amateur, who died this year on July 24th. The prize, of a value of £1000, will be awarded for the most meritorious contribution to innovation in yacht science made by an amateur researcher.

Nominations for the prize, which is open to anyone of any country, whether or not they are members of the Society, should be submitted to the Secretary of the Amateur Yacht Research Society, BCM AYRS, London WC1N 3XX, to arrive by 1st September 2001. Nominations should be supported by evidence of the merit of the work done, peer review if any, details of publication (which may be in a recognised journal, or the Internet), and all other information that may be of use to the Prize Committee. If the work or any part thereof has been supported by grants or other funds, full details should be given. Receipt of such funds will not in itself be a bar to nomination, but since in part the purpose of the prize is to encourage work by amateurs, it is a consideration. Research carried out as part of normal employment will not normally be eligible. All information received as part of a nomination will be treated in confidence.

Award of the Prize will be adjudged by a Committee chaired by Mr. George Chapman, who is himself distinguished by his contributions to sailing hydrofoils and marine instrumentation, and a long-time friend of John Hogg. The award will be announced at the London Boat Show, January 2002.

The Amateur Yacht Research Society acknowledges with gratitude the generosity of the Hogg family that has made the establishment of the AYRS John Hogg Memorial prize possible. John Hogg's writings in AYRS publications rank with those of, for example, Edmond Bruce and Harry Morss, and are a lasting memorial.

He was a good friend to the Society who will be sorely missed.

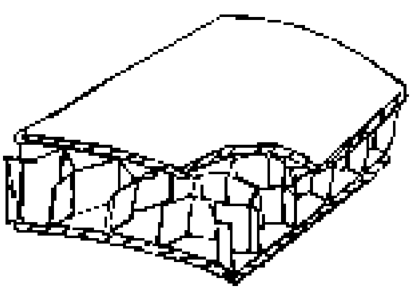
On the design of long thin surface piercing hulls

Robert Downhill

In the quest for more speed of catamarans the only way to reduce drag is to make the hulls with as small a cross section as possible consistent with adequate buoyancy, structural strength, and stiffness. Buoyancy is easy to calculate, as is structural strength, but structural stiffness is not.

To state the obvious "When designing long thin hulls it is essential to maintain the shape of the hull under all loading conditions."

O.K. where do we start?



Possibly the best type of structural concept for maintaining the shape is monocoque honeycomb cored sandwich construction using fibreglass face sheets as complex shapes can be made relatively easily using fibreglass molds and vacuum bagging techniques.

Layups can be made which incorporate varying thickness skins to provide reinforcing and basic strength where required while maintaining the outside shape while the interior of the hull varies.

Assembly is in the manner of plastic model aeroplanes.

The structure is broken down into easily manufactured components which are then stuck together with glue.

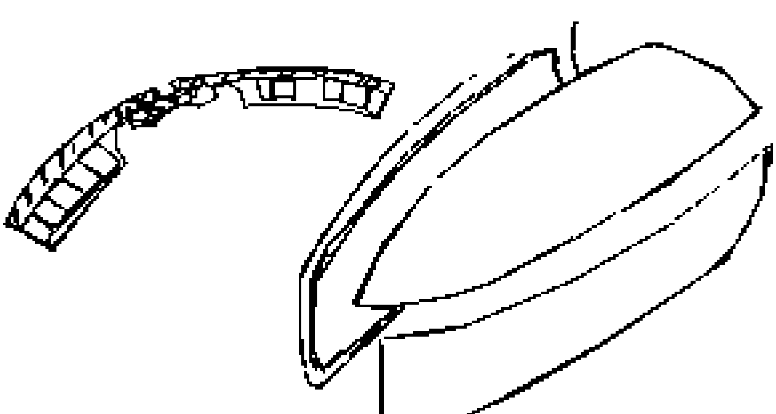
Below is an example of how this would all go together for a three segment assembly.

Before we get to the manufacturing bit someone has to say how thick all the various parts have to be.

You cannot make up a boat with all the skins the same thickness as the loads are never the same at any two parts of the structure although that is a good place to start.

John Perry built Crusader that way in his back garden and highly successful it was too. Crusader had 1600 sq ft of sail area was 52 feet long and some 25 feet wide and weighed 2.5 tons..

I asked him where he got the design from and he told me it was a Tornado scaled up by a factor of 2.5 – knowing John I believe him.

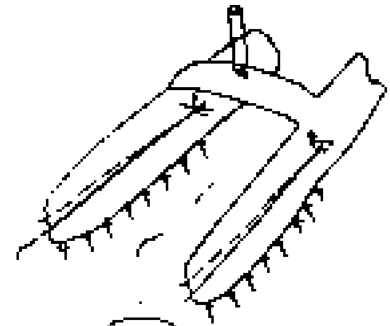


He built it in his garden on Eel Pie Island in 1977 from wooden false work from the inside out so the external finish left something to be desired.

The construction was foam filled sandwich about an inch thick with local reinforcing as required for the attachment of stays etc and there was not a bulkhead any where.

In 15 knots of wind it did over 20 knots. I know because I measured it using a calibrated trailing log speedo.

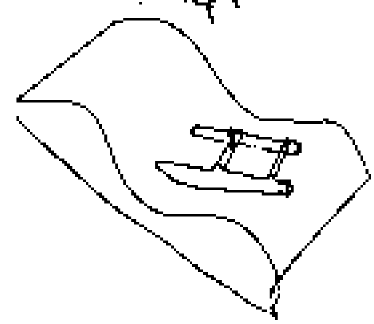
Right then on to the nitty gritty.



The loading cases for a boat are many and the combinations of load cases are also many. The first load case that springs to mind is the boat sitting on the water. This produces up loads on the hulls equal to the weight of the boat.

With the sails set and moving forward side forces are applied to the hull (or the dagger boards) to equal the side force from the sails. The forward thrust causes a pitching moment that shifts the centre of pressure of the water forward and hence puts more loading on the bows.

Another more interesting load case is the boat broaching at high speed in the trough of a wave as the bow buries itself in the next wave causing the boat to yaw causing it to experience high side loads on the forward hulls.

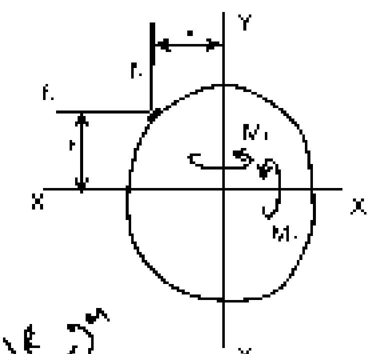


You can (and should) go on like this building up primary load cases until you cannot think of any more.

Each of these primary load cases are completely balanced i.e. the boat is always in equilibrium in all 6 degrees of freedom. For dynamic cases the mass and mass moments of inertia counteract some or indeed all of the unbalanced externally applied hydrodynamic and aerodynamic loads.

Knowing all the external applied loads the internal loading in the structure can be obtained and the boat can be stressed to obtain the sizes of all the bits of structure that contribute to the structural model of the boat.

This brings us up to the subject in the title – long thin monocoque unbraced hollow structures subjected to side loads.



The basic formulae for calculating stresses assuming plane sections remain plane is: $fm/y = M/I = E/R$

where fm = stress produced by the bending moment M
y = distance of the fibre from the neutral axis
M = Moment applied to the section about the neutral axis
I = Second moment of area of the section about the neutral axis
E = Hooks modulus of elasticity
R = Radius of curvature produced by the moment M

Also of course: $fa = P/A$ where
fa = the stress produced by end load P
P = the end load applied to the section
A = the area of the section

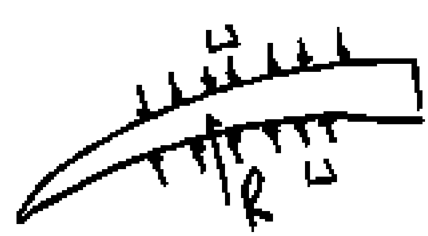
And by inference: $fs = S/A$ where
fs = the shear stress produced by shear load S
S = the shear load applied to the section
A = the area of the section

There are two axes about which bending takes place and the stresses have to be added to get the total stresses when working out the primary and combined loading cases.

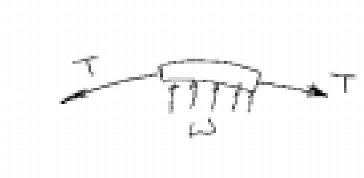
Keeping it simple then lets go back to the original objective — how to maintain the shape under load. The probability is the cross section of a bow section is elliptical and a quick look at possible external loadings would reveal modes of deformation of the section caused by local loads.

The next obvious investigation must be the effect of the accumulation of load on the overall structure. Finally the effects of the overall loading deformation on the local deformation load has to be considered.

About this point you are probably wondering what I am talking about but if you bear with me it all should become clearer.



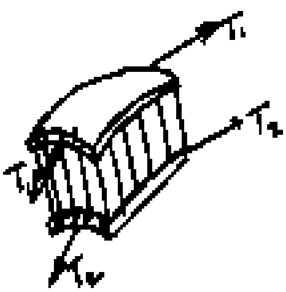
In the formulae for stress, the radius of curvature refers to the shape a beam takes when subjected to an applied moment. This moment produces stresses through the section and the stresses when multiplied by the area of any particular section gives the end load at that point in the structure. Because of the curvature of the section the tension or compression in the skin of a thin section requires that a force W is applied perpendicularly to the skin equal to fa•A / R – or more regularly quoted as



T/R where T is the end load in the skin.

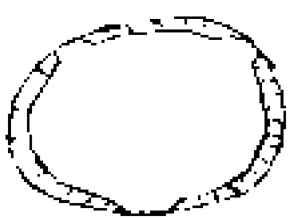
So if you look down on a long thin hull subjected to side load then the two outside skins apply loads which tend to flatten the section. As the section flattens the moment of inertia gets less , the stresses increase, the loads get higher and eventually the section flattens completely.

If you want to see this in action get a drinking straw and apply a bending moment at each end and watch the mode of failure.



Naturally if there is already curvature built in during manufacture this modifies the loading but the cross section of the hull must have bending stiffness to withstand the crushing loads. Additionally if honeycomb construction is used the difference of loading between the inner and outer skins must be chosen carefully such that the differential forces do not exceed the crushing strength of the core. If you have a thin outside skin and a thick inner skin ostensibly carrying all the major bending of the hull, it is possible for the skin to come away from the core.

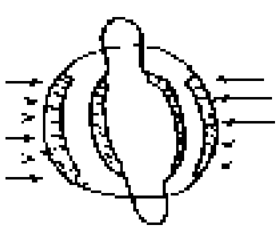
Naturally the radial stiffness of the cross section has to have no more than three thin sections or the ring stiffness is lost by the structure becoming a mechanism which will be unable to withstand any radial unbalanced loads.



Enlarging a bit on methods of assembly it is worth mentioning good and not so good designs, bearing in mind the structural ramifications. The first example of a cross section is one with three seams longtitudinally which translates in structural terms a frame having three pin joints. It is fairly obvious that this section will not collapse.

The sandwich construction provides longtitudinal bending stiffness and if the joints are not too thin then local deformation is not significant.

The same line of reasoning applies to a section with two joints to make up the hull. Where this type of construction is useful is the designer has a lot of freedom to make the moulds for laying up the sandwich making sure there are no reentrant angles which would interfere with the vacuum bagging that is almost mandatory for making this type of structure.



Proceeding on the line of reasoning if the joints are made flexible or indeed in the more general case of an unsupported thin shell structure then it is not difficult to visualise the various modes of failure that can occur.

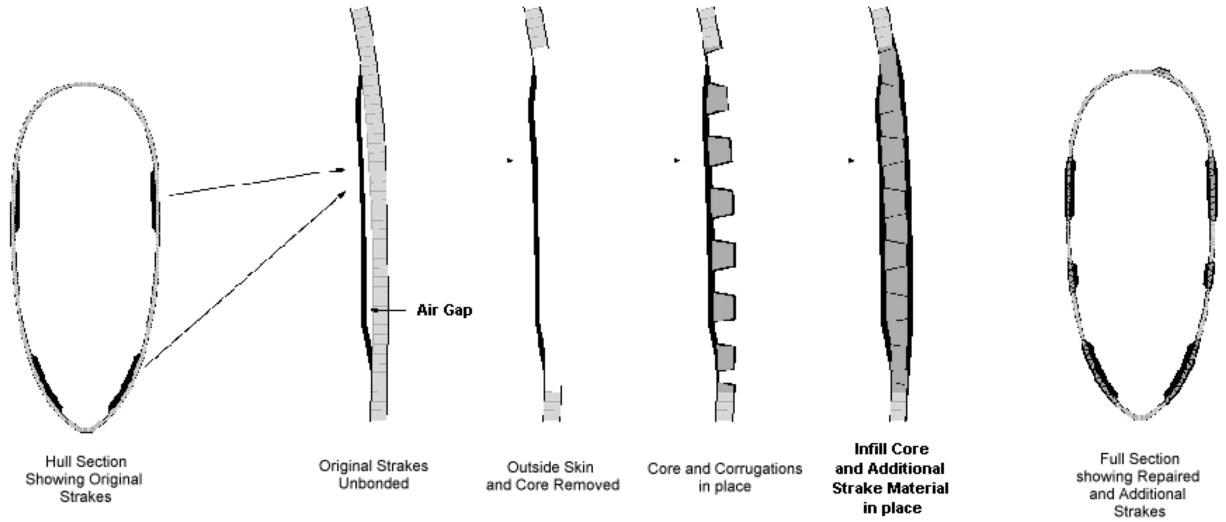
The example shown here is reinforced top and bottom with thin shell sides. Water pressure crushing loads would combine with structural overall loading to cause early catastrophic failure. Reinforced sides would encourage the thin shell to bow upwards and downwards, which in turn would reduce the moment of inertia to a point where large cracks would appear where the thin shell was forced into a small radius of curvature.

People think that the process of design is checking the worst stressed areas and making sure those bits do not fail. Most boats are much too bulky and there is a built in safety factor which saves the reputations of the less famous designers. You know the sort of thing the first time the boat goes out the odd failure occurs here and there with attachments of stays to hulls cleats and the like. However when you get to really cutting down the safety margins you get into the realms of having to pay attention to every part of the structure.

Compare the thicknesses of aeroplane fuselages and the average yacht. If the average passenger examined the structure of a Boeing 737 stripped of the interior furnishings he or she would be appalled at what little held them 30000 feet up in the air.

Interestingly enough if you use a computer program for calculating the stresses the resulting radial stiffness requirements indicate relatively high radial moments of inertia are needed which do not appear when you strain gauge sections. When displacement of the cross section is taken into consideration the radial bending stiffness required is of the order of 10 times less than the calculations show and effectively build in a safety factor the designer does not know about.

What went wrong, and how *Team Philips* was repaired



Team Philips, as we now all know, came into difficulties on March 29th 2000 during her sea trials when a 45ft portion of the port hull became detached. She was towed back to Totnes, Devon and was taken to the build site so that repair work could begin.

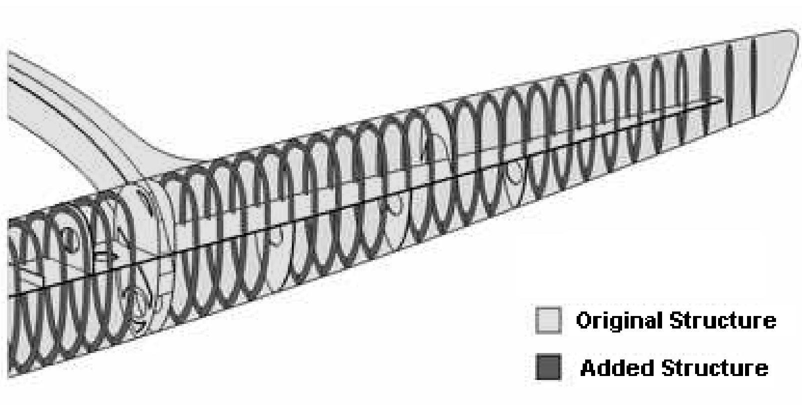
A full structural survey showed that the 45 ft port bow section of Team Philips failed due to a production problem. On each side of each hull, and along most of their length, there were two longitudinal carbon strakes (strips) which are positioned to take the transverse and vertical load on the hulls. The survey established that the strakes were not fully bonded to the Nomex honeycomb core and therefore were unable to take the compressive and tensile loads applied to them during the sea trials.

We have heard that although the hull was surveyed using ultrasonic testers prior to launch, the "bubbles", effectively the whole length of the strakes, were so large that the equipment failed to detect the edges.

The solution involved work inside and outside of the hulls. The unbonded strakes were accessed from the outside of the hulls by removing a 405 mm wide strip of the outer carbon skin and the underlying Nomex core from one end of the hull to the other. The new additional structure consisted of a longitudinal corrugation of carbon/foam core which provided a shear link between the inside and outside hull skins.

Additional longitudinal carbon strake material was applied to the outside face of the corrugations to produce a relatively slender beam with balanced sections. These strakes are subject to very high endloads, both tensile and compressive, as they react to the hydrodynamic loads generated by the hulls as they pass through waves.

To prevent buckling, a number of lightweight ring frames were bonded every 0.6 metres to the inside of the hulls. These frames were produced from 3D design software, and were cut by water jet from sheet foam in segments. The basic laminate was completed in the factory and the segments passed into the boat through the deck hatches for assembly and final taping to the inner skin of the hull.



FERRO-CEMENT REPORT

R Michael Ellison

Since our previous articles on ferrocement construction there have been a number of changes so a brief update and account may be useful to someone considering purchase or even building a ferrocement craft.

Most surveyors now refuse to report on ferro-cement hulls, and for this reason only third party insurance is available. Without either destroying or ultrasound testing the entire hull, it is not possible to say beyond doubt that there are no voids and so they will not sign. If the hull was built and plastered under survey this seems very unfair.

Blue Circle is my third ferro yacht. She was given to me as a derelict, having fallen over when one of her legs broke, and she was holed in the bilge. Experts did not agree on the best method of repair. The way I chose was fast, not expensive, and has worked well for three years including rough weather offshore and drying out on my tidal mooring (without legs as it's mud). Other methods may have worked as well, but I worried about fresh cement bonding to the 1976 original.

I enlarged the hole to sound non-rusty rods and mesh then removed all loose cement. I straightened the bent rods and tied in extra where the old ones were rusty. I replaced mesh with new wire. Then complete and strong — the strength is always in the armature — I mixed epoxy resin with ordinary cement powder and plastered over the sole, fitting a water intake in case a future owner should want a water cooled engine. The cement powder is only a filler but it makes the repair the same density as the original, hit the hull with a hammer and you will not find the repair (hence the caution by surveyors?). Frost has not caused any problem. Blue Circle is now for sale, finished.

Because of the lack of insurance, ferro cement yachts are inexpensive. This should be a warning to everyone not to build a new yacht in this material without some exceptional reason – buy second hand but be very careful and decide in advance what you need.

My previous 'concrete boat' was a 38' shell lying in a quarry. I worked on it for a while but I could not complete the job by the time, in 1995, I had to sell to raise money to fight a court case with my bank. In 1999 that problem was resolved, not by lawyers but by Robin Fautley FCA who audits the AYRS accounts. In the meantime, several owners had also failed to make further progress on the hull, and "it" was again for sale in January this year. (Can you call a concrete structure, with rust and some 20 extra holes "it"?). Its condition was not good — I have not seen the last survey report but it certainly frightened the yard where it was stored, and neighbouring yacht owners, who all felt it was too dangerous to be moved — especially by crane over their boats! In part it may be that the yard stood to lose £ 10 per week and the neighbours would no longer have a chance to steal anything. She became mine on 1st February.

This second (fourth?) concrete boat (CB2) will become "Sea Bee II" if I complete the work to get her seaworthy. Target for this is October. I have an engine, a Lister 20 h.p. with starting handle. I am about to install 2 tons of ballast and have bought 40 pigs — iron ones weighing 56 lbs each. I hope my brother is making a rudder and I think I have fixed the keel. This hull seems to be built using pipes instead of rods. Beside the flat steel keel plate a pipe was laid on each side. These, especially the port one, had rusted and the concrete around had been crushed. The two worst areas were aft where the keel has been in wet ground for 12 or more years, and forward where the main support was probably not wide enough. I know that for long periods the hull was full to the stern tube with rain water so very heavy. Note: avoid hulls made with pipes if you can. I hope I have cured this by inserting a steel rod for reinforcing concrete right along the pipes from aft, coating them with cement as they went in. I then chipped off all the external rust and loose cement and applied a thick coat of epoxy and cement mix. When filled and faired, I plan to paint with epoxy tar to the waterline. On Blue Circle this has been very satisfactory – tar does show through the antifoul in places but it's not a worry to me.

When ferro cement hulls are built, the mesh and rod (or pipe) "armature" has to be suspended, so that the cement can be applied in one non-stop operation all over the hull. Adding this extra weight often causes the mesh to move. Port and starboard quarters of CB2 are not the same shape. Mainly this is above the waterline, and as I can only see one side at a time, I shall not worry; but just maybe "she"(having become a boat) will try to sail round in circles. Foam sandwich yachts are also sometimes different. This is due to having a wood frame and heaters to bend the foam or cure the glass. If the heat is not even (just hot sun on one side is enough), the wood bends towards the heat.

If, like me, you find a derelict cement shell suitable for use as a swimming pool, can it become a boat or are the surveyors correct? If it has a substantial iron keel I can see no reason why it should break in half when lifted. CB2 has a ferro deck and coaming so is very unlikely to fold inwards unless very tight slings were used without spreaders. The prediction that it would sink is presumably due to the holes drilled by surveyors plus holes for water cooling, toilets, drains and whatever. I found 20. I missed two, which were quickly filled from inside with epoxy putty as the water came in. They would probably have taken a week to fill the hull if left. A hull holds an amazing amount of water, but free surface can be a problem, as it all rushes forward or aft, and can hit the bow or a bulkhead at just the "wrong' moment in a wave cycle. 'Just in case' I secured some drums of water in the keel space as baffles.

Ian Hannay our past Chairman has sailed many thousands of miles with his ferro schooner 'Melina' and he has lent her for several Speed Week meetings at Portland. Unlike CB2, "Melina" has a plywood deck, which saves weight giving greater stability. Wood is prone to rot where damp and Ian had to undertake major repairs when he bought 'Melina". At 40', Ian can easily bring her in and out of Weymouth Harbour to anchor in Portland on his own. For less money than CB2 is likely to cost to build I was offered a concrete 46' ferro yacht with the added bonus of a trip to Tenerife to collect her. I declined on the grounds of size. From 38' or 40' to 46' everything is much bigger and costs more. Single handing would be possible with mechanical aids, but raising the anchors or the sails becomes a serious task. Running costs in paint, harbour dues, heavier ropes and slipping costs all take a steep step upwards without any great increase in passage speed, range or benefit for the purpose I expect to use the boat.

I accept that I cannot get insurance to cover any personal loss so I cannot take the family silver to sea. Not a real worry as it was sold to pay for legal battles. I have a hull that is heavy, and, due to weight of deck, has only a moderate stability, therefore a low rig or perhaps kite power is desirable. I have chosen an air cooled diesel engine for hand starting, fuel economy, low revs (shaft max 1000 rpm) and it can heat the cabin. I have to live with the noise and low astern power.

Some of the ferro yachts for sale have been well made, well maintained and are very suitable for extended cruising. They are, in my opinion, excellent value, but, when you sell, will your investment be returned? I hope to have a craft suitable and safe to cruise to Azores and the West Coast of Scotland at least, at reasonable cost, and to last a few years. Other ferro yachts look rough, have been badly fitted out and need major work to complete. I decided to build what I want on a hull I consider to be the right size having a fair finish and pleasing shape.

For my purpose and intended cruising waters, I considered multihulls both two and three hulls. Passages would be faster, safer and more comfortable. I looked at two or three possible craft, but it seems that 40' is minimum to carry fuel, stores and a diesel engine. At these sizes, life in port becomes more difficult with just one or two people. A multihull will sit comfortably upright on mud or sand giving a great advantage in using drying moorings; but I would not be happy to go ashore leaving my "home" at anchor in some remote bay — even with fathoms of chain they tend to blow about. The final choice was due to the ferro hull being offered, and I did not, nor have I since, heard of a suitable low cost multihull that could meet my needs.

Michael Ellison's sailing biography runs from wooden dinghies to singlehanded transatlantic racing, and is too long to summarise! He was once the Administrator and is now the Chairman of AYRS.

Maxed Out with Five Masts:

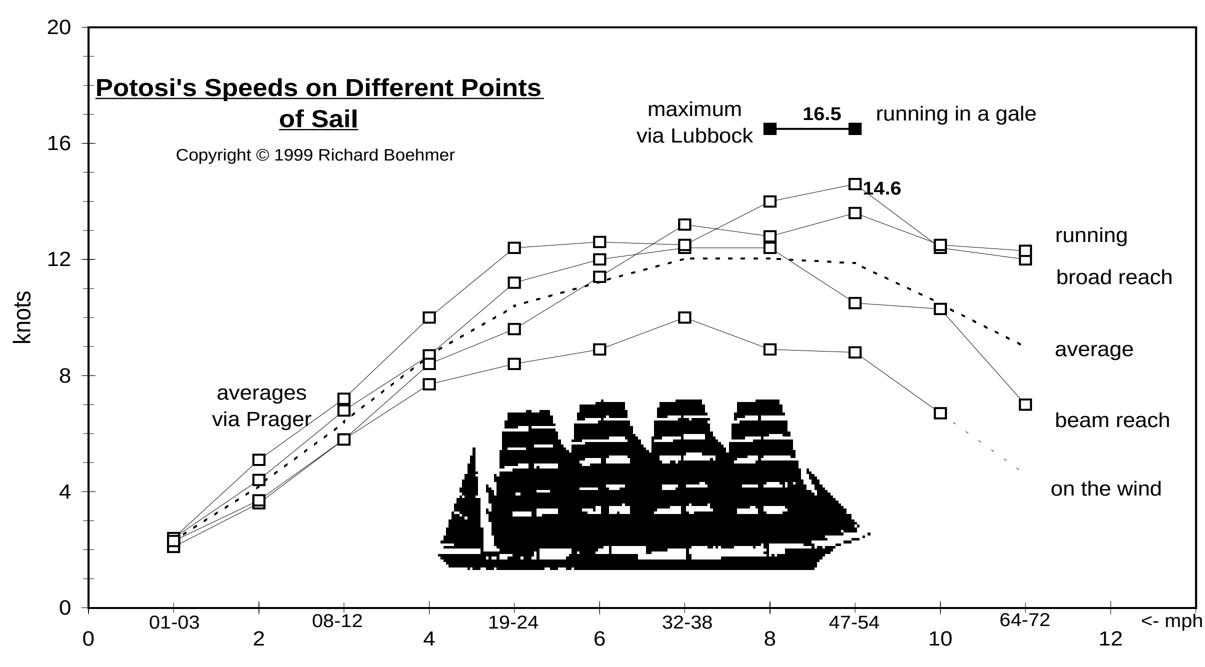
Examples of Peaks in Maximum Speed

The performances of yesteryear's commercial sailing vessels can offer us insights into the performances of our recreational sailing boats or "yachts" (as in AYRS).

Searching for actual polar data (ship or boat speed vs. wind speed and direction) not just hypothetical or VPP-generated polar diagrams, I dug into my files and came up with an article by Wagner (1) that I first found over 20 years ago. Although this article was written in German, a language whose sixteen "the"s baffled me in my freshman year of college many years ago, I could understand the illustrations and some of the text with the help of a German to English dictionary. Now, one of Wagner's data sources interested me. With the help of a local library's Inter Library Loan service, I obtained a photocopy of this nearly century old article written by another German, Prager (2).

Prager presents a wealth of tabulated performance data (ship speed vs. wind conditions) for 13 wooden barks, 13 wooden ships, 13 steel ships, 11 four-masted steel barks, the five-masted bark POTOSI, and the five-masted ship PREUSSEN. These last two gigantic German sailing vessels were built totally of steel: hulls, masts, yards, stays and halyards. Furthermore, the POTOSI and PREUSSEN had built-up amidship decks so that the crew could safely work the ship traveling at full speed in gales. For comparison, the accompanying Table (overleaf) presents the dimensions of these two and all the other five-masted square riggers plus a few other sailing vessels known for their size or speed.

For the POTOSI and the PREUSSEN, Prager presents the ship's average speeds for four passages each. These averages are given in decimal knots, one value for each of four apparent wind directions and for eleven Beauford wind forces; therefore, for each ship he gives 176 (4 passages x 4 wind directions x



11 wind forces) speeds. The highest values for each of the 44 wind conditions are plotted in the two accompanying Figures.

Although the plots of Prager's data clearly show that these two vessels did their best in gales (Force 7-9) and were slowed in full gales (Force 10), for their maximum speeds we need to look elsewhere. For the PREUSSEN, we have a marvelous book (3) in which the author, Horst Hamecher, presents not only lists of all the daily positions and mileages for each of the PREUSSEN's thirteen voyages but also a selection of abstracted watch logs that contain date, watch time, distance traveled (divided by four equals speed), heading, and wind direction and force. A search through Hamecher's abstracted watch logs yielded the data also plotted in the accompanying Figure for the PREUSSEN that maxed out at 18.25 knots for one four hour watch.

For the POTOSI, I could only find Lubbock's (4) statement that "the five-master covered 650 miles in 48 hours with an easterly gale behind her. In one [4 hour] watch she sailed 66 miles, giving an average of 16.5 knots." Because the specific force of the gale was not stated, this speed has been plotted for the middle two gale forces. Note that POTOSI's best day's run of 378 nautical miles exceeded the PREUSSEN's 369 nautical miles.

The simple conclusion drawn from these plots is that a sailing vessel's speed increases as wind speed increases - up to a point - then it decreases! For two of largest of all sailing vessels to have ever sailed the seas, their speed peaked in medium gales; then they slowed down as the wind speed further increased. This same situation obviously exists for smaller sailing vessels but at lower wind speeds. This decrease in speed is caused by either the skipper's and the crew's prudent handling of their vessel (reduction of sail to trailing of warps) or by their continuous and dangerous loss of control of the vessel.

In either case, sailing vessels have a maximum speed ultimately dictated by nature.

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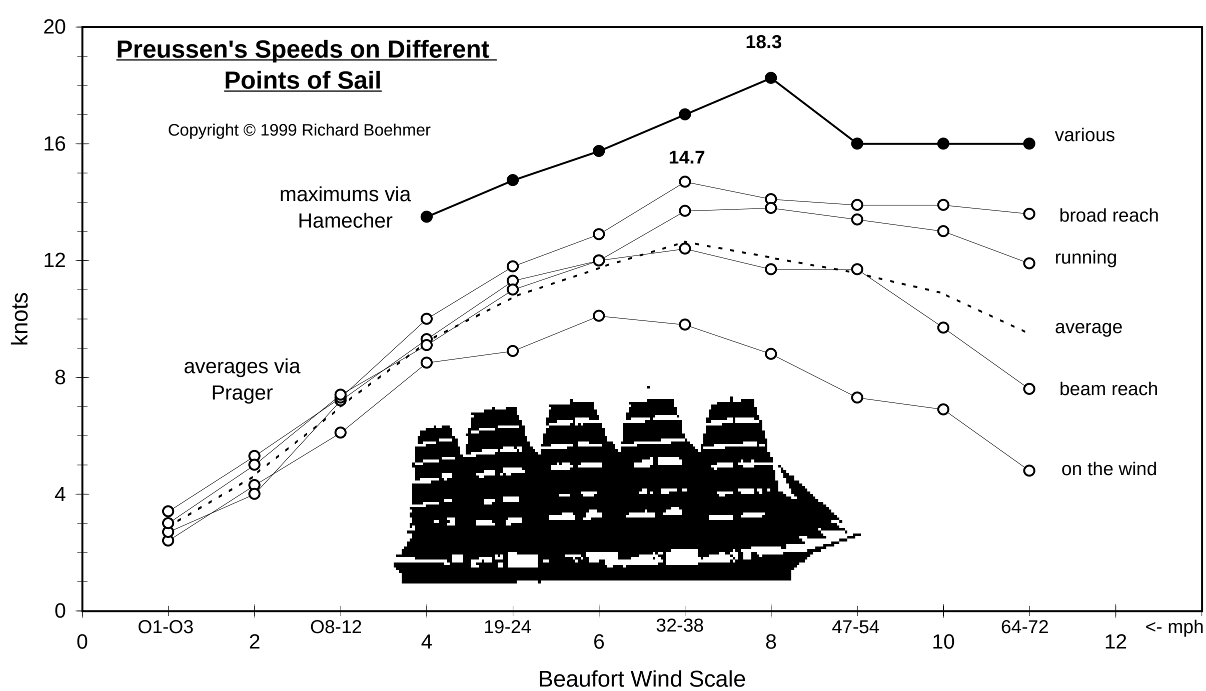
2. Prager, M., 1905, Die Fahrtgeshwindigkeit der Segelschiffe auf großen Reisen, Annnalen der Hydrographic und Maritimen Meteorologie XXXIII (January 1905), pp.1-17.
3. Hamecher, H., 1969, Königin der See Fünfmast-Vollschiff «PREUSSEN», pp.356-366.
4. Lubbock, B, 1932, The Nitrate Clippers, p71.

Silhouettes of POTOSI and PREUSSEN are redrawn after Alan Villier's (1971) The War With Cape Horn.



The 5 Masted, Square-Rigged Sailing Vessels and Other Commercial Sail Superlatives

	type	material	built	launch-loss	length ft.	breath ft.	depth ft.	Tonnage gross	Tonnage net	d.wt.	Disp.* tons	Sail Area sq. ft.	crew	BDR n.m.
PREUSSEN	5m ship (only)	steel	Germany	1902-1910	437.00256	53.608272	27.099408	5081	4765	8000	11150	59800	48	369
FRANCE II	5m bark (largest)	steel	France	1911-1922	448.81344	55.806408	28.21488	5633	4543	8000	11800	68300	45	420
R. C. RICKMERS	5m bark	steel	Germany	1906-1917	439.95528	53.64108	30.445824	5548	4696	8000	11700	54100		
POTOSI	5m bark	steel	Germany	1895-1925	366.30132	49.70412	28.477344	4026	3854	6300	8600	50600	44	378
KJØBENHAVN	5m bark (last)	steel	Scotland	1921-1928	366.891864	49.310424	26.90256	3901	3329	5200	7900	56000		305
MARIA RICKMERS	5m bark	steel	Scotland	1891-1892	374.99544	47.998104	24.999696	3813	3344	5500	7900	57000		
FRANCE (I)	5m bark (first)	steel	Scotland	1890-1901	360.986424	48.785496	25.885512	3784	3304	5900	7800	49000	46	
THOMAS W. LAWSON	7m schooner (only)	steel	USA (MA)	1902-1907	395.3333333	49.25	25.5	5218	4914		11300	43000	18	
WYOMING	6m sch. (largest)	wood	USA (ME)	1909-1924	329.5	50.1	30.4	3730	3036	6000	7600	38500	12	
GREAT REPUBLIC **	4m bark (largest)	wood	USA (MA)	1853-1872	335	53	38	4555		6000	9700	70400	130	413
CHAMPION OF THE SEAS	3m ship (fastest)	wood	USA (MA)	1854-1876	252	45.5	29	2447			4800	56200	110	462
CUTTY SARK	3m ship (last clipper)	comp.	Scotland	1869-pres.	212.5	36	21	963	921		2133	32700	32	360

* The displacements of PREUSSEN, KJØBENHAVN, and CUTTY SARK are from references; the others are estimates based on their tonnages.

** GREAT REPUBLIC's measurements are as built; cut down to 3357 gross tons after fire.

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Power Alternating Sailing (PAS)

– A Proposal for a New Way to Sail Directly Upwind and Downwind

Peter A. Sharp

Sailboats are much faster when sailing across the wind (reaching) than they are when heading upwind or downwind. This difference is generally accepted as a normal part of sailing. We believe that difference might be substantially reduced, and this paper introduces a potential solution: Power Alternating Sailing (PAS). PAS craft might be able to sail directly upwind and downwind at speeds that are faster than the speed of the true wind, and faster than the velocity made good (VMG) upwind and downwind so far achieved by other types of sailing craft. (Readers will have to judge for themselves whether the various PAS craft described below would actually function as presented, since no testing or mathematical analysis has been done.)

Explanation

The PAS principle is quite simple. However, it can be embodied in at least four general types of craft, and some may be difficult to understand because of the relative motions involved. In its most basic form, Type 1, PAS would make use of twin vehicles, each with a wind turbine mounted on it, and some means to transmit energy between the two vehicles. One vehicle remains stationary, with its wind turbine "on", and sends its energy to the other vehicle. The other vehicle moves forward at a high speed, with its own wind turbine "off", and configured to create as little drag as possible. Then the two vehicles switch functions. In other words, they sail as a team by alternating which one produces power while stationary, and which one uses that power while moving forward. So this process is referred to as "power alternating sailing", or "PAS".

A simple analogy with PAS is the way a person's feet move forward when walking. The stationary foot is used to propel the moving foot forward, and then they switch functions. While one foot is stationary, the other foot moves forward at about twice the speed of the person's body. The person's body moves forward at the average speed of her two feet. In principle, PAS is as simple as walking or running. PAS craft can move in any direction, but the principle offers a potential speed improvement primarily when moving upwind and downwind, since these speeds are currently much lower than when reaching. However, it may eventually be possible for PAS water craft to achieve average reaching speeds which exceed those of current water sailing craft.

Obviously, PAS vehicles must be designed for minimum aerodynamic and hydrodynamic drag, and minimum inertia. The cycle times should be as long as possible so as to minimize the time spent accelerating and decelerating. Special attention should be paid to means of conserving and regenerating energy during the transitions from one part of the cycle to the next.

Before presenting examples of the four general types of PAS craft, we will briefly review the other techniques which are currently available for sailing upwind and downwind. The emphasis will be on wind turbine boats, and also on vertical axis wind turbines (VAWT), since PAS makes use of wind turbines (or the equivalent), and VAWT may offer some advantages. At present, there is only one proven technique for going directly downwind faster than the wind - the Bauer technique - so we will discuss that technique in order to establish the context for PAS.

Other Techniques for Sailing Upwind and Downwind

The common knowledge seems to be that ice yachts are able to move downwind, and even upwind, faster than the wind by following a zigzag (tacking) course at high speeds. Hugh M. Barkla calculates that ice boats achieve a velocity made good (VMG) downwind of about 2.4 times the speed of the wind, and upwind they achieve a VMG of about 1.4 times the speed of the wind. Land yachts are also able to exceed the speed of the wind in this way, at least downwind. Water craft using hydrofoils or skis and sails or traction kites should be able to achieve a VMG downwind faster than the wind, although we have found no confirmation as yet. Upwind, we are not aware of any water craft which can achieve a VMG greater than the wind speed.

A windmill boat or windmill land yacht can move directly upwind because its power is initially higher than its drag. (When stationary, the power of the wind turbine is proportional to the cube of the wind speed, whereas the drag is proportional to the square of the wind speed.) So far as we are aware, no windmill boat or windmill land yacht has exceeded about .5 the true wind speed into the wind (achieved by Jim Bates' boat, Te Waka, in 1980 using a horizontal axis wind turbine, or HAWT). This is primarily because the wind turbine itself creates so much drag while producing power. (The essence of PAS is to separate power from drag, to "divide and conquer" this problem of wind turbines.)

Nevertheless, the low speed ratio upwind for windmill craft is somewhat puzzling given that relative speeds upwind in excess of the wind speed are possible in theory (see Reg. Frank, and A. B. Bauer). Perhaps no one has made a serious attempt to sail directly upwind faster than the wind because of the especially high rotor efficiencies and very low vehicle drag that would be required. So far, windmill boats seem to have a top speed of roughly .5 the wind speed in all directions. By tacking, fast multihull sailboats can currently achieve a VMG to windward that is only a little better than windmill boats. So on water (and even on land), sailing directly upwind faster than the wind would represent a significant achievement.

For windmill boats, the best speed to windward requires a variable pitch for both the wind turbine and the water propeller, and probably a variable gear transmission as well. The wind turbine operates at reduced power (and at a reduced tip speed ratio) so as to achieve the best thrust to drag ratio (as explained by B. L. Blackford). A large water propeller similar in appearance to an airplane propeller is required for high efficiency. (Consequently, a large, modified, model airplane propeller, while not ideal, was used by Peter Worsley for the water propeller of his windmill boat, which was powered by a variable pitch HAWT via a multiple speed bicycle gear transmission). The most efficient water propellers have been developed for human powered speed record boats, where maximum efficiency is critical.

A vertical axis propeller with a continuously variable cyclic pitch may also be used. This type of propeller is sometimes called a Voith Schneider propeller, but other types of blade pitch control are possible, such as that used by Giusseppe Gigliobianco. The leading edges of his VAWT blades were joined, using short shafts, to the leading edges of the vertical axis water propeller blades, with the result that they controlled each other's cyclic pitch angles when moving directly into the wind. (For higher efficiency, his blades should perhaps have been counterbalanced using a counterweight out in front of the air blades.) Variable pitch fin drives (vertical or horizontal) could be used instead of rotating water propellers, and these may eventually prove to be more efficient and easier to construct than variable pitch propellers. Varying the cyclic blade pitch of oscillating fin drives would be relatively simple. Also, a VAWT might be made to function as an air propeller during downwind operation if it were controlled like a Voith Schneider water propeller.

In the context of both windmill boats and PAS craft (which use wind turbines), experimenters may wish to know that, while there are many types of VAWT, the class of "mass balanced" cycloturbines (or giromills), with self pitching blades (like those of Sicard, Sharp, and Kirke), seem to be the most efficient. They are equal to conventional HAWT, according to wind tunnel tests and a mathematical model developed by Kirke and Lazauskas, two Australian engineers. The Sharp turbine is inherently the lightest of these, which implies that it is the most responsive to large and rapid changes in the wind velocity, and it has good starting torque, so it should, on average, achieve the most energy conversion. (Models have been constructed as bearingless rotors.) The Sicard VAWT, and the Sharp VAWT (and hybrids of these two) are simple for amateurs to construct in model sizes, although fine tuning them at full scale would require adapting the mathematical model developed by Kirke and Lazauskas. (A working explanatory model of the Sharp VAWT can be made in about 5 minutes using common office materials).

To pitch their blades so as to maintain an efficient angle of attack, these mass balanced VAWT achieve a dynamic balance between centrifugal force (acting on a mass) and aerodynamic lift (acting on the blade), which both rise and fall at a similar rate (by the square of the ground speed, and the relative air speed, respectively), so instantaneous differences between the two are used to pitch the blades and to maintain them at an efficient angle of attack. In 1978, a wheeled model powered by a Sharp VAWT (4 ft. in diameter, 2 ft. blade span, 4 in. blade chord) easily went directly upwind. But it was not built for optimum performance (no streamlining, a fixed gear ratio, only 2 blades), and the speed ratio to windward was estimated to be not more than 0·5.

Other potential advantages of mass balanced VAWT for windmill boats and for PAS craft include: 1) good starting torque, 2) always oriented to the wind; 3) a lower center of pressure than HAWT (a VAWT can be much wider than tall, thus allowing a larger swept area and more power); 4) the blade orbit can stay clear of the deck and crew; 5) the straight, symmetrical blades can be allowed to pivot freely so as to fully feather them, thus permitting the turbine to be quickly turned "off" and "on" while rotating; 6) the blades (by tilting their bottom ends outward, as suggested by Rainey), and/or the horizontal support arms for the blades (functioning like a helicopter rotor, with the pitch controlled by surface runners or by vertical air vanes), can be used to create an aerodynamic balancing force to counteract heeling and/or to create lift; and 7) for reaching, the turbine can be stopped with the vertical blades oriented to function as wingsails (first done by Gigliobianco around 1993), and with the horizontal support arms functioning as wings so as to counteract the heeling forces and/or to create lift.

The Bauer "Faster Than The Wind" Vehicle

Most people who are familiar with Newton's laws of motion are sceptical about the possibility of sailing directly upwind and downwind faster than the wind, but it was first done, downwind, 30 years ago by Andrew B. Bauer. As reported to Bauer by Donald L. Elder, discussions at the University of Michigan around 1950 considered whether or not a vehicle could go directly downwind faster than the wind using the basic approach that Bauer later confirmed. In the interim, Elder found that most aerospace engineers considered the idea to be a form of perpetual motion. In fact, Bauer's manager at the time, a well-known aerodynamicist, may have motivated Bauer to resolve the question when he said to Bauer, "I bet that you can't get wind in your face." Bauer was one of the very few people who believed it could be done.

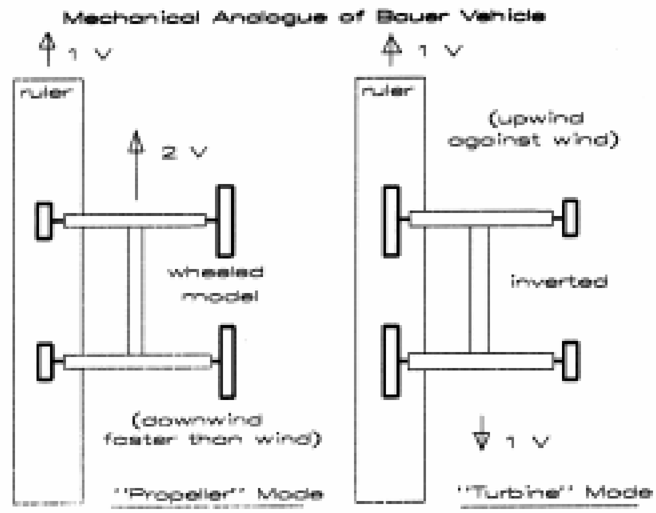
C. A. Marchaj, in Aero-Hydrodynamics of Sailing, states that a wheeled vehicle built by Andrew B. Bauer went directly upwind faster than the wind. That claim is inaccurate. According to Bauer, his vehicle was designed only to go directly downwind faster than the wind, and it did so in February of 1969, as he reported in his 1969 article. The speed of Bauer's vehicle upwind was 6 mph in a 12 mph wind, which was achieved when merely backing up the vehicle for another downwind run.

However, when going directly downwind, Bauer's vehicle, with Bauer driving, reached a speed of approximately 14 mph in a 12 mph wind during a sustained run of 40 seconds, thus outrunning the speed of the true wind. Briefly, the vehicle achieved speeds of about 15 mph in a 10 mph wind. Bauer stresses that, due to the steep wind gradient near the ground, the altitude at which the wind speed and the vehicle speed are measured must be appropriate. Our own recommendation is that, to facilitate comparisons between different types of vehicles, both measurements should be taken at the height of the center of pressure of the propulsion device. Otherwise, to use an obvious example, a vehicle pulled by a traction kite could exceed the wind speed as measured near the ground, while the kite was actually moving slower than the wind speed as measured at the altitude of the kite. And near the supporting surface, as for models, differences of only a few feet can make a significant difference.

Bauer's technique for sailing downwind was to use a variable pitch (180 degrees), two bladed, horizontal axis propeller (with moderate blade twist), 15.4 feet in diameter and mounted at the rear of the vehicle, which was a simple wood frame with a plywood seat and foot rests. The propeller was coupled to a single bicycle wheel via a twisted bicycle chain, using a fixed gear ratio. The blade pitch was controlled by a hand lever hanging vertically in front of the rider, and the rider used his other hand to steer by moving a very long tiller extending to the small front wheel. Two small side wheels were used for balance.

When accelerating downwind, the pitch of the propeller blades, initially operating as a wind turbine (even though the blade twist is in the wrong direction), is gradually reversed so that the rotor becomes a propeller powered by the wheels. Then the vehicle is able to continue to accelerate and exceed the speed of the true wind. (In his 1969 article, Bauer also explains how a boat could use its water propeller as a turbine to spin the air propeller.) In practice, the transition from turbine mode to propeller mode is smooth and continuous. This is perhaps so because, at that speed ratio, the spinning rotor would still create propulsive drag, like a drag sail pushing the vehicle, even if the rotor were not connected to the wheels. The Bauer vehicle can be stopped quickly by reversing the blade pitch.

On Dec. 14, 1995, Bauer demonstrated his downwind technique in a most remarkable way at the office of Paul B. MacCready, President of Aerovironment (near Los Angeles, California), and



winner of the Kremer Prize for human powered flight. Bauer placed his model, which had a 20 inch diameter, 4 bladed, fixed pitch propeller, on a 5 foot long conveyor belt that he had constructed, and which included a variable speed motor. The demonstration took place in a windless room. The model was held in position on the moving belt until the propeller was spinning at full speed. When released, the model was easily able to advance against the direction of the belt faster than the belt was moving (8 feet per second).

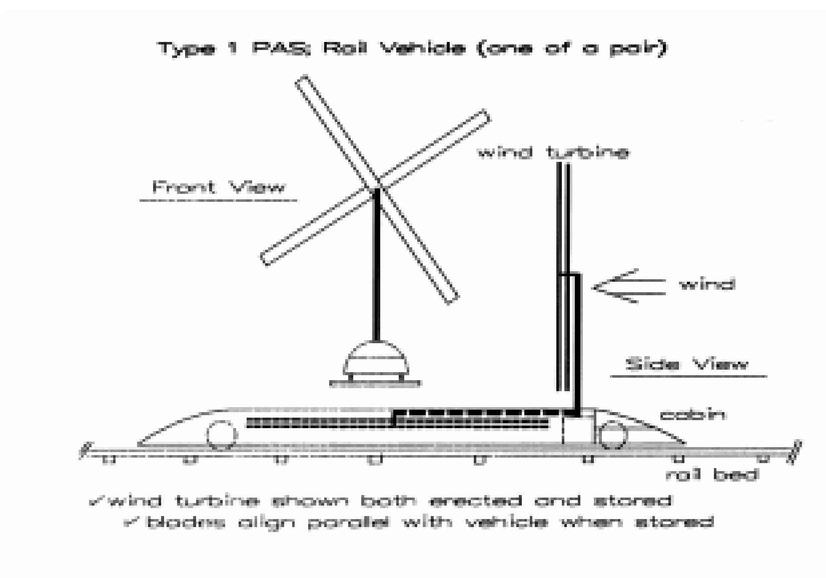
The speed of the belt could be slowed until the model stayed in its original position, or the belt could be slowed further, causing the model to be carried slowly along in the direction of the belt. In other words, the Bauer technique works better as the belt speed (or wind speed) increases. For the model on the moving belt, the same relative motions exist as when the ground is stationary and the wind is moving. For a wheel-driven propeller, the two situations are equivalent. So when the model is holding its position on the belt, it is moving at the speed of the "wind". When it is advancing faster than the speed of the belt, against the direction of the belt, it is moving "downwind faster than the wind".

In his 1975 text, Technical Yacht Design, Andrew G. Hammitt explains the Bauer technique, and he includes a photograph of Andrew Bauer's vehicle with Bauer beside it. Unfortunately, neither the text nor the photograph's caption credits Bauer, which inadvertently creates the impression that the vehicle is Hammitt's. Hammitt reports, "A tuft on the front of the vehicle was used to show the apparent wind direction. The vehicle went downwind fast enough so that the tuft indicated a head wind indicating that it was exceeding wind speed." One of Hammitt's graphs shows the power coefficients for the downwind operation of both a wind turbine and a wheel-driven propeller. The two curves cross, like a wide "X", where the vehicle is moving downwind at about 0·6 times the speed of the wind, indicating that above that speed ratio, the propeller mode is increasingly more effective than the wind turbine mode. (Figures in Bauer, and Frank, show this same transition point.) Bauer states that a crossover point of 0·6 gives optimum acceleration. That photo of the Bauer vehicle may also be found in "*Crackpot or Genius?"* by Francis D. Reynolds.

Research papers on windmill ships and boats now take for granted the possibility of sailing downwind faster than the wind using the Bauer technique. But since the Bauer technique is difficult for most people to understand and accept (AeroVironment, Inc. has received many letters from people still insisting that it is impossible), an explanation using a simple analogue model may be helpful. The relative motions may be more easily understood using an analogy that does not include a wind turbine or a propeller, or the motion of fluids, such as air or water.

Our abstract analogue model is inspired by two devices built by Theo Schmidt. The analogue model has two pairs of wheels which are fixed to their axles, and the axles rotate. But the wheels on one side are only half the diameter of the wheels on the other side. The small wheels are placed along a board or plank, such as a ruler, which is itself lying on a smooth surface, such as a table, and the large wheels rest on the table.

Assuming good wheel traction, if the ruler is pushed lengthwise at a speed of 1V (V here means the speed of the ruler), the model should move twice as fast as the ruler (2V), and in the same direction. The ruler pushes the small wheels, and the small wheels push the large wheels, causing the large wheels to roll. In turn, the large wheels (because they are larger and have a longer moment arm) rotate the small wheels. The ground speed of the large wheels (2V) equals the speed of the ruler (1V), plus the speed of the small wheels relative to the ruler (1V). That is, 1V+1V=2V. The ruler is analogous to the wind, the small wheels are analogous to the



conventional techniques. And finally, for sailboats, upwind performance rather than downwind performance is the area needing the most improvement. The Bauer technique is, in our opinion, a third step toward realizing the potential of using wind turbines for sailing. Sailing directly upwind was the first step, and using a wind turbine as an autogiro sail was the second step. And PAS might become a fourth step.

The following descriptions of the four types of PAS vehicles are intended only to convey what may be possible, not what is practical. Consequently, not all the details are included, only the basic concepts. It is assumed that any competent technical person could fill in the details.

wheel-driven propeller, and the large wheels are directly analogous to the original vehicle wheels.

The abstract model can also be used to illustrate how a wind turbine can move upwind against the wind. If the model is inverted so that the large wheels now ride on the ruler (we will ignore the vehicle lean that results), and then the ruler is pushed again in the same direction and at the same speed (1V), the vehicle should move backwards against the direction of the ruler at 1V (and 2V relative to the ruler). That is, 2V-1V=1V. This configuration is analogous to a wind turbine vehicle moving directly upwind at the speed of the wind. In this case, the ruler is analogous to the wind, the large wheels are now analogous to the wind turbine, and the small wheels are now directly analogous to the original vehicle wheels.

Higher speeds might be reached both “upwind” and “downwind” by adjusting the relative wheel sizes (the gear ratio) of the model. Note that in both of these analogies, the power is derived from the difference between the “wind” speed (ruler) and the ground (table), not the difference between the “wind” speed and the vehicle speed.

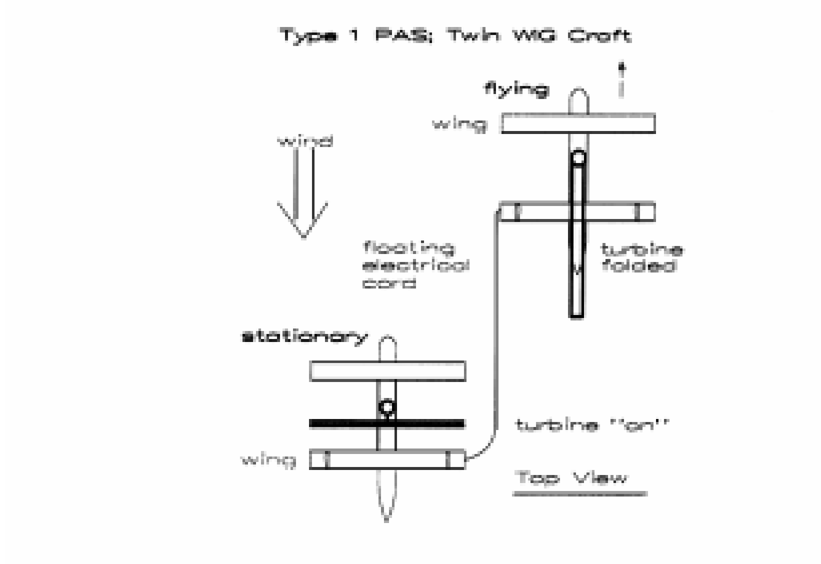
The 30 year existence of the Bauer technique raises a question: Why have no boats been built which use this technique, even though theorists now accept the principle as valid? The explanation seems to be that although the technique is remarkable in itself, the all-round performance of windmill boats, so far, has not been particularly impressive. The technique seems limited to a narrow range of downwind angles. Except perhaps for ships, it does not seem to promise a significantly better downwind performance than might be obtained with more

Type 1 PAS: Twin Rail Vehicles

Now we will consider the PAS technique and its potential speed advantages for going upwind and downwind. This example is intended only to illustrate the PAS principle in a clear manner, and to explore its potential, since the application itself would be impractical except for demonstration purposes. In this imaginary example of PAS, two streamlined vehicles on railroad tracks work as a team. A horizontal axis wind turbine (HAWT) is mounted on each vehicle. Each HAWT has two sets of blades (for gyroscopic balance), and both sets can be aligned parallel with the turbine’s tower structure for storage. Each HAWT produces energy only when its vehicle is stationary with its brakes locked. That energy is transmitted, via a third rail, to the other vehicle, which is moving at high speed up the track. But before moving, its HAWT, with its blades parallel to its tower, is lowered and stored inside the vehicle so as to reduce aerodynamic drag to a minimum.

We will also assume that the necessary mechanisms (not shown) for quickly storing and erecting the wind turbine, and for stabilizing the vehicle when stationary, are installed and are under the control of an engineer in the cabin of each vehicle. To reduce the weight aloft of the wind turbines, so as to permit quick raising and lowering, we will assume that the electrical generators are located within the vehicles. We will assume that the track is level and that it heads directly into the wind, and that the wind is blowing at 15 mph.

Consequently, we may also assume, conservatively, that the moving vehicle, with its turbine lowered and stored, travels at a speed of 60 mph, or 4 times the speed of the wind (ground speed). So its air speed is 5 times the speed of the wind, or 75 mph. This seems to be a reasonable speed to assume since we know that even a human being, with a very low power to weight ratio, can pedal a carefully streamlined human powered vehicle (HPV) at over 68 mph, the official record of the International Human Powered Vehicle Association. In a 15 mph wind, a specialized wind turbine should be able to achieve a far higher power to weight ratio than a human being, even if the electrical transmission efficiency is only 50%. And the aerodynamic drag of the streamlined vehicle, with its wind turbine stored, would be quite low. If more power were required, the wind turbine could be made arbitrarily larger, since its power would increase faster than the power required to propel it (when stored in its vehicle).

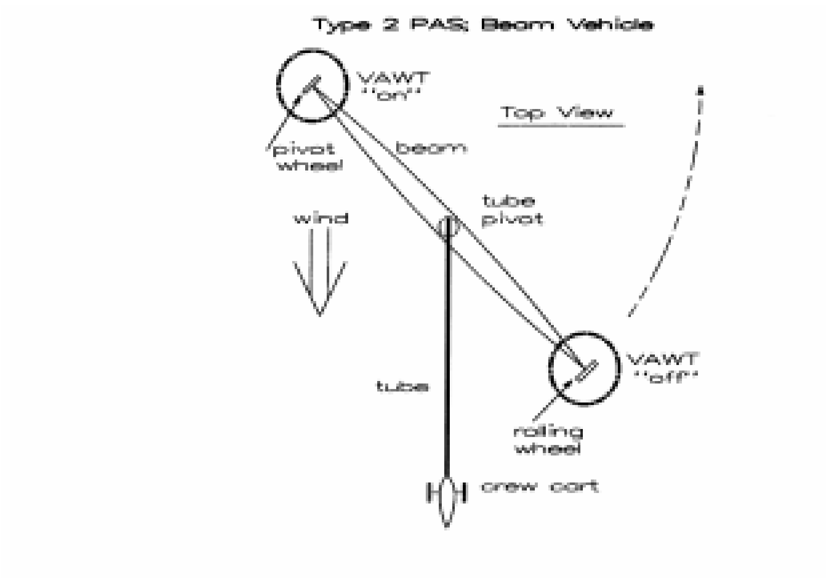


The PAS principle is applied in the following manner: The lead vehicle, using energy sent to it, and with its wind turbine stored, speeds down the track for many miles, and then pulls off onto a siding and stops. There, it locks its brakes, quickly erects its wind turbine, and transmits electrical energy back to the rear vehicle. The rear vehicle simultaneously turns off its wind turbine and quickly lowers it into a stored position. Then the rear vehicle accelerates to 60 mph, eventually passes the lead vehicle, and continues speeding down the track for many miles until it is able to pull off onto another siding. There, it stops and sends its energy back to the other vehicle. This procedure repeats until both vehicles reach their common destination.

At the end of the journey, we calculate the average speed of the two vehicles working together. That speed is roughly half the average speed of one vehicle, or about 1/2 of 60 mph, or approximately 30 mph. That means that both vehicles, powered only by each other's wind turbines, have gone directly into the wind at a combined average speed close to two times the speed of the wind. This average speed ratio upwind (2.0) would be considerably faster than the speed ratio to windward achieved even by ice boats (1.4). It would be about four times the speed ratio that a windmill vehicle has achieved so far (.5). While in theory a self propelled windmill vehicle might achieve this speed ratio, its design and construction would be extremely difficult, if it could be done at all. In contrast, these PAS vehicles would be relatively easy to construct using current technology since they would be, basically, just an electric train powered by a stationary wind turbine.

The two vehicles could work together to go back down the track, in the same direction as the wind, at an even higher speed, since the moving vehicle would experience much less aerodynamic drag than before. The apparent head wind when going downwind would be 30 mph less than when going upwind, so the downwind speed would be about 30 mph higher, or roughly 90 mph (not considering the relatively small increase in rolling friction). The average downwind speed of the two vehicles would be about 45 mph, or roughly 3 times the speed of the true wind. Again, this speed ratio downwind (3.0) would be faster than that of ice boats (2.4). And it would be about two times the best speed ratio briefly achieved by Bauer (l.5).

However, the Bauer vehicle might improve its speed ratio as the wind speed increased, as in the example of the model on the moving belt. And the average speed ratio of the PAS vehicles would decrease somewhat since, other things being equal, the proportion of time spent traveling at full speed between transitions would decrease. In other words, the time required for PAS transitions would take up a larger proportion of the total travel time. On the other hand, if the PAS vehicles simply went farther



of PAS craft. And, when reaching (and perhaps even when going upwind and downwind), PAS craft might combine other sailing techniques with PAS to further increase their speed.

Type 1 PAS: Twin Craft on Water

On water, this same basic technique might be used. Again, this example is intended to show what may be possible, not what is practical. The two craft might fly just above the water using wings in ground effect ("WIG"; examples of such craft may be found on the Internet) when moving at high speeds (with hydrofoils or a hovercraft hull for take off), and a sea anchor (possibly a water turbine and temporary water ballast) or a bottom anchor (in shallow water) when converting wind energy. The two craft are connected by a very long, well insulated, electrical wire, which always floats still on the water, that is reeled in and out only by the moving craft (so as not to drag the wire through the water). Since the use of an electrical wire on water would be unwise due to the possibility of shocks, plus the hazard of other boats cutting it, the concept is not very practical. But it might work well enough in open water for the average speed upwind and downwind to substantially exceed the speed of the true wind. (The same technique could be used on land and ice.)

Given the much higher power required on water than on land, some form of "power kites" might be used instead of conventional wind turbines. A power kite would generate power by sweeping back and forth across the wind at high speed (perhaps under computer control using various sensors). Small wind turbines are mounted on the kite (perhaps tip vortex wind turbines, which have been used on a small airplane to recover 20% of the energy normally lost to wing tip vortexes). At high speeds, the wind turbines can be quite small and still produce high power, since their power is proportional to the cube of the speed of the relative wind, and kites can achieve air speeds of 100 mph. The electrical wires are then held out of the water by the power kites. The wires connect each craft to each kite. The moving WIG craft tows its kite, with

between transitions, they could retain their speed ratio.

Even higher speed ratios might be possible using PAS since there are ways to increase the power to drag ratio of a PAS vehicle team. For instance, in this example, each PAS vehicle could be constructed as a train with many cars, and each car could be equipped with its own wind turbine. When operating the wind turbines, the cars would be spread out along the track (about 10 turbine diameters apart, as is done on wind farms so as to avoid interference effects), thus multiplying the power of each train an arbitrary number of times. But the cars would close up into a normal train configuration when moving (with the gaps between cars covered to minimize drag), so as to cause only a relatively small increase in aerodynamic drag over that of a single vehicle (car).

In the above example, if the wind were blowing from the side of the track, the average speed ratio of the twin PAS vehicles would be somewhere between their average speed ratios upwind (2.0) and downwind (3.0). Just for the purpose of comparison, consider that with the wind coming from the side, if each vehicle used an efficient wingsail, they could move simultaneously at a speed exceeding 4 times the speed of the wind, as was demonstrated by the Amick Windmobile. It is for this reason that when sailing across the wind (reaching) windmill boats and PAS craft would, in most cases, revert to the use of direct sailing techniques (wingsails, autogiros, traction kites, etc.). On the other hand, as the above example illustrates, there is no obvious limit on the average speed ratio the kite in a low drag configuration. But even power kites would be suitable only in open waters.

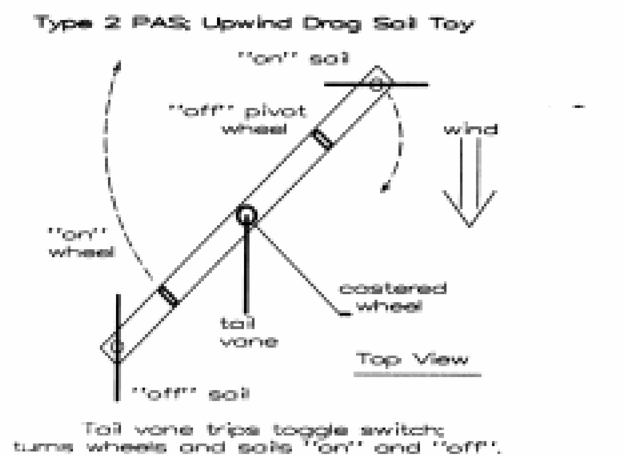
Type 2 PAS: A Single Vehicle With Two Alternating Wind Turbines

Type 2 PAS vehicle configurations require only a single vehicle with two wind turbines (or the equivalent) which alternate their "off" and "on" cycles. Their speeds would probably be lower than that of twin PAS vehicles, due to more frequent cycles. The two wind turbines move forward one at a time (when "off", and configured to produce minimum drag), but both are mounted on the same vehicle - on long, parallel guide tracks, or at the ends of a very long beam that moves forward like a double ended paddle, etc.

An example: A wheeled vehicle using an extremely long beam has a Sharp VAWT, and a drive wheel, at each end of the beam. Each VAWT powers the drive wheel at the other end of the beam, through a clutch. Power is transmitted using mechanical means - drive shafts, or chains, or cranks and cables, etc. Each end of the beam alternately swings forward through about 90 degrees of arc. The crew, in a separate streamlined cart, is towed using a very long tube, which is pivoted at the midpoint of the beam. (The tube also serves to prevent the beam from tipping in response to wind pressure on the VAWT.) This arrangement would minimize the inertia of the ends of the beam. (Over water, the beam might function as a wing in "ground effect" to reduce or eliminate the water drag of the advancing end of the beam.)

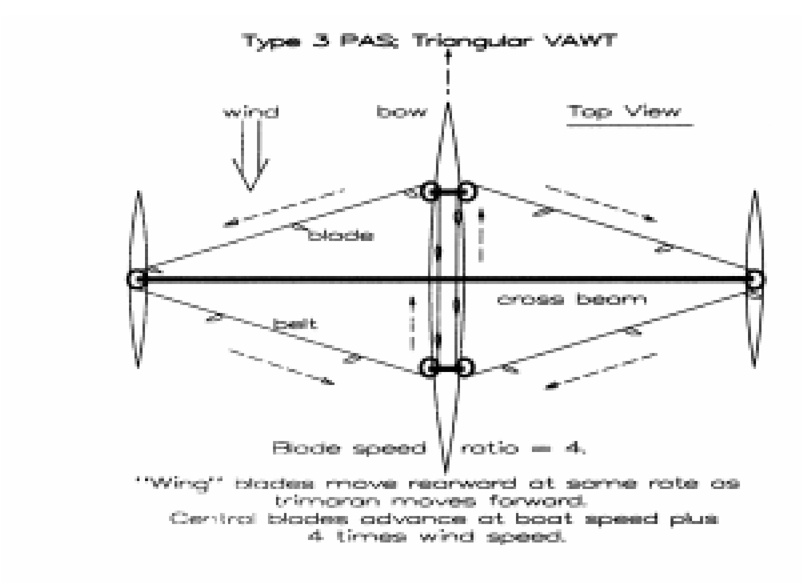
The crew requires at least two control lines. Each control line turns one wind turbine "on" and the other turbine "off", while connecting the "on" turbine to its drive wheel, and disconnecting the "off" turbine from its drive wheel, plus applying a brake to the stationary wheel, which acts as a pivot for the beam. So the "off" turbine continues to rotate but produces no power, and low drag. Turns are made by swinging one end of the beam forward more than the other end. As mentioned previously, special attention should be paid to techniques for conserving and regenerating energy.

Even drag sails could be used to go directly upwind, although the vehicle would be just a curiosity, a toy, and its speed ratio would probably be less than 1. It would use a long beam as a "lever" to advance into the wind in a manner somewhat similar to the example directly above. The long beam has a pivoting drag sail at each end, and a wheel mounted at about 1/4 beam span from each end. A castered "tail" wheel (for stability) is mounted on a short tube extending out behind the middle of the beam. The drag sail at one end is pivoted perpendicular to the wind, while its wheel is locked and serves as a pivot to swing the other end of the beam upwind until the beam is at about a 45 degree angle to the wind. The advancing drag sail is turned parallel to the wind for minimum drag, and its wheel rolls freely. And then, in turn, the other end of the beam swings forward 90 degrees in the same manner. A wind vane mounted at the middle of the beam is used to trip a mechanical toggle switch, which turns the drag sails and the wheel brakes "on" and "off" when appropriate.



Type 3 PAS: A Single Vehicle with Power Sources Which Cycle On and Off WHILE Continuously Moving

This type of PAS vehicle can be confusing, so we will consider both a complex example and a simple example. The complex example of a Type 3 PAS vehicle is a wide trimaran equipped with two VAWT, which are triangular (in plan), both always "on", and which rotate a water prop. Two such triangular VAWT are mounted side by side to form a wide diamond shape (in plan), rather like the outline of



wings as wide as the trimaran. Each wing leg is about twice as long as its base leg. The base legs are above the central hull of the trimaran. Both VAWT always face toward the front (bow) of the trimaran, when moving either upwind or downwind. Each turbine uses vertical blades (wingsails) supported between two continuous belts, one above the other, that form the triangular outline of each VAWT. (The tip speed ratio of the blades would be about 4, and a control belt would collectively adjust their pitch angles by loosening or tightening their main sheets.) The blades move forward (always toward the bow of the boat) only when they are on the shorter base legs. On the base legs, the blades move directly into the wind (they are “off”) when the boat is moving upwind, and directly away from the wind when the boat is moving downwind. The belts always move in the same direction.

Thus, the blades produce power only when they are on the wing legs of the triangles - moving out and back and rearward relative to the boat when moving upwind, and the same when moving downwind. The result is that when the blades are producing power, they do not advance relative to the water, so as to avoid the usual increase in rotor drag when moving upwind, and the usual decrease in rotor power when moving downwind. In other words, each blade moves rearward, while producing aerodynamic lift (they are “on”), at the same rate that the boat moves forward. So each blade, when producing lift, would function like the blade of a stationary HAWT, or like a sailboat reaching back and forth directly across the wind, while the boat itself was heading upwind, or downwind, as fast as the speed of the wind. If, when producing lift, each blade traced a line on the water, the blades would leave a stepped sequence of straight lines, or rows, perpendicular to the boat and advancing in the direction of the boat, both upwind and downwind.

The simple example of a Type 3 PAS vehicle is just a toy. It would go only downwind, and it would be unlikely to go downwind faster than the wind since it uses only drag sails. But it would probably go directly downwind faster than is possible using conventional drag sails, and it is of interest for that reason. In this case, the two power sources are two drag sails that alternately open and close, while they also move forward and rearward relative to the front wheels of the vehicle, since they are mounted at the trailing ends of crank arms connected to the two front wheels.

The two crank arms are connected to outside faces, near the rim, of the two large front wheels, which are fixed to a common axle. The crank arm pivots are offset 180 degrees from each other, so one crank arm moves forward while the other moves rearward (relative to the front wheels). At their trailing ends, the crank arms are each supported by a small wheel. Above each small wheel is a tall rectangular sail which opens and closes like a book (binding forward). The sails open in response to a tailwind, and close in response to a headwind. When closed, they have a streamlined shape facing downwind.

At the point where a rolling wheel touches the ground, that point has no forward movement. Consequently, a crank arm pivoted near that point will momentarily come to an almost complete stop relative to the ground. A sail mounted at the other end of the crank arm would therefore also come to an almost complete stop, and that would subject itto high drag from the wind, thus giving the sail, and the wheels, a strong push (even if the wheels were moving faster than the wind). So the sails push the wheels, and the rotating wheels, in turn, oscillate the sails. This “pumping” motion of the sails functions like a very crude sort of propeller, which would be more obvious if the vehicle were placed on a moving belt in a windless room. Seen in that context, this toy PAS vehicle might be described as somewhat similar to the Bauer vehicle - but using only a drag type “propeller”, rather than a lift type propeller like the Bauer vehicle. (An implication of this similarity is that there may be a more general principle that includes both PAS and the Bauer technique.)

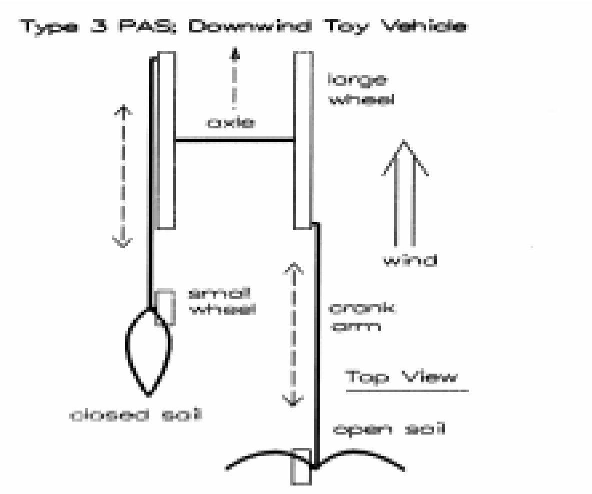
Type 4 PAS: A Single Vehicle Using an Accumulator for Brief Energy Storage

A single vehicle with a single wind turbine (or the equivalent) could briefly accumulate (store) wind energy while stopped, or moving at some angle to the wind, and then propel itself using that accumulated energy directly upwind or downwind with its wind turbine "off" and in a low drag configuration. Functioning in this manner, the vehicle might be able to exceed, on average (including the time for energy accumulation), its VMG upwind and downwind whilst using wind energy only for short instants. This technique would require the use of a highly efficient energy accumulator (and vehicle), but one with only a relatively small energy capacity, such as rubber bands, vacuum pistons, super capacitors, flywheels, or perhaps even compressed air if combined with an extremely efficient ball piston type compressor/ pump/motor and good thermal insulation (see the "Ball Piston Engine" on the Internet). Note that a land yacht would function as a wind turbine if the rotation of the wheels were used to charge an energy accumulator.

A Note on Testing PAS Models

Since determining if a vehicle is moving upwind faster than the wind is difficult, that difficulty may have inhibited amateur research in this area. So we would like to suggest a possible way to measure the upwind (and downwind) speed ratios of model PAS vehicles. A PAS test model is raced against a battery powered model electric vehicle whose motor is controlled by a sensitive air switch (perhaps using a disc, counterbalanced so as to cancel inertial and gravity effects). A tailwind turns the switch on, and a headwind turns the switch off. The result is that the model electric vehicle maintains a downwind speed very close to the speed of the wind.

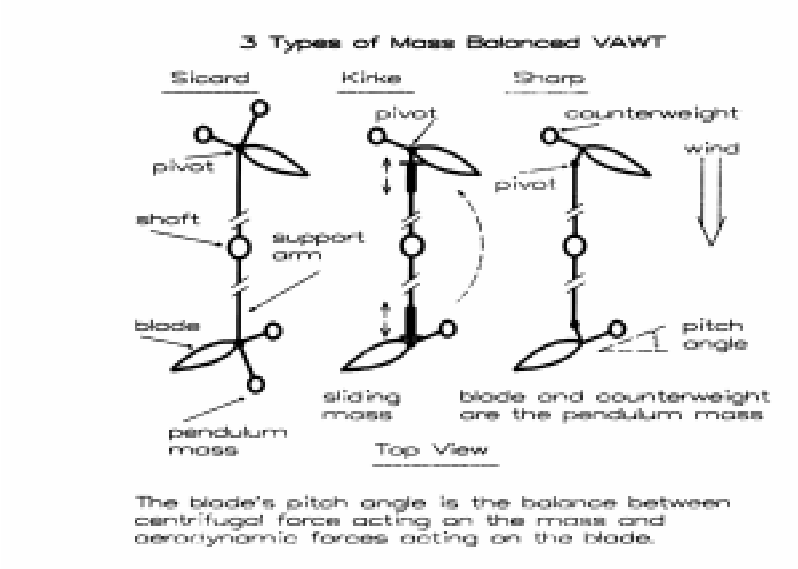
The electric vehicle pulls, and is steered by, a long "clothesline" cord loop (with pulley wheels at each end) oriented parallel to the wind's dominant direction. A bright marker is attached to the side of the "clothesline" that moves upwind, and the marker moves upwind at the same speed as the model electric vehicle moves downwind. A PAS test model moving upwind therefor races the marker to determine its speed ratio. While the upwind speed ratio of the marker would be less accurate (except for the moment when the electric vehicle and the marker were passing each other), it would still provide a good approximation if many tests were averaged. The racing aspects of this technique should appeal to students of all ages. Variations of this technique might be used over water.



Conclusion

We have presented four general types of PAS vehicles: Type 1: twin vehicles, each using a wind turbine of some kind, which alternately stop (when "on") and go (when "off"). Type 2: a single vehicle carrying two wind turbines which alternately stop (when "on"), and go (when "off"). Type 3: a single craft, with power sources which continuously move forward (when "off") and rearward (when "on") relative to the craft. And Type 4: a single vehicle which briefly accumulates energy while stopped or moving at some angle to the wind, and then uses that energy to move directly upwind or downwind.

These types suggest that there are many ways to embody the PAS principle, and some would work much better than others. There may be additional types. These present types might also be classified using other criteria. So at this present stage of conception, formulating a precise definition of PAS would be premature. Our hope is that PAS will provide a new framework for integrating modern sailing innovations (wingsails, hydrofoils, wind turbines, traction kites, etc.) so as to create sailing



craft with high performance on all points of sailing.

Acknowledgments

While no endorsement of the PAS principle is implied, we wish to thank the following individuals for their generous help in preparing this article: Dr. Andrew B. Bauer, Theodor Schmidt, Dr. Paul B. MacCready, David Culp, Dr. Fiona M. Sinclair, Frank R. Bailey, Charles M. Brown, Peter Worsley, Dr. David Gordon Wilson, Brian Kinlock Kirke, and Anne Bolla.

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Kirke, Brian Kinloch: Australian patent #AU-B-79418/91, 1991, “An Improved Variable Pitch Vertical Axis Wind Turbine”. Blade pitch is controlled by a small mass forced radially inward against centrifugal force when each counterweighted blade, pivoted at its leading edge, pitches in either direction in response to its local relative wind. The patent cites the Sicard patent as prior art, but not the Sharp patent, which is an oversight of the patent search. While the pitch control system is an improvement over non mass balanced systems (springs, eccentrics, cams, etc.), it does not seem to us to be an improvement over the mass balanced systems of Sicard, and Sharp.

Kirke, B. K. and Lazauskas, L: “Experimental Verification of a Mathematical Model for Predicting the Performance of a Self-Acting Variable Pitch Vertical Axis Wind Turbine”, Wind Engineering, Vol. 17, No. 2, 1993. A note of caution about mass balanced VAWT in general: Larger mass balanced VAWT might require that the mass used for balancing each blade be divided and placed on opposite sides of the rotor so as to avoid gravity effects on the mass when heeled, and the possibility of resonant vibrations due to the masses moving radially inward and outward during normal operation, especially when a retreating blade “flips” to its opposite pitch angle. But small mass balanced VAWT do not seem to vibrate, and their blade pitching is not noticeably degraded by moderate amounts of heeling, probably because centrifugal force is so high relative to the force of gravity.

(For boats, reduced power at high heeling angles might be used to limit heeling). Also, 3 blades (which produce 6 small, overlapping drag pulses per revolution) should always be used so as to avoid strong rotor drag pulses, as when using 2 blades (which produce 2 maximum drag pulses per revolution), so as to avoid inducing resonant vibrations.

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Sicard, Charles Andre: USA patent #4,048,947, Sept. 20, 1977. A mass balanced VAWT. A small mass located radially outward from, and attached to, the leading edge of the counterbalanced blade is the balancing mass. It functions like a short horizontal pendulum which responds to centrifugal force. Alternatively, the blade counterweight and the pendulum mass may be combined into a single mass mounted forward of, and outward from, the blade. His patent Fig. 5 shows inefficient blade pitch angles, which implies that he did not know how to balance his blades correctly, and perhaps never did. He also used too many blades, and his starting technique was poor. But these errors could be easily corrected.

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Multihull Yacht Performance Prediction

Joseph Norwood, Jr.

In looking back through AYRS #120, I can see that I stopped short of making Chapter 2 as useful as it should have been. Please accept the present article as a belated appendix.

There are two key equations in that chapter. The first was a fourth order (quartic) algebraic equation for the ratio of boat speed to true wind speed, V_B/V_T, which characterizes light-air performance.

$$X^4 - a^2[C_L\sin\gamma - C_D(X + \cos\gamma)]^2(X^2+2X\cos\gamma+1) = 0 \quad (1)$$

where

$$X \equiv V_B / V_T \quad (2)$$

and γ is the course angle with respect to the true wind, C_L is the lift coefficient of the rig, and C_D is the drag coefficient of everything above the water. a is defined as:

$$a = (\rho_A/2\alpha)(A_SL/W) \quad (3)$$

where ρ_A is the mass density of air ($\rho_A = 2.38\times10^{-3}$ slugs/ft^3), and $\alpha = 0.01$ sec^2/ft is a parameter of the hull drag curve (see AYRS #120 for the details). A_S, L, and W are the sail area, waterline length, and weight or displacement of the boat in ft^2, ft, and pounds respectively. Hence

$$a = 0.119\,(A_SL/W) \quad (4)$$

It is possible to solve Equation (1) analytically, but the algebra involved is probably not worth the trouble. The solution can be iterated very quickly on a programmable calculator.

For purposes of comparison, let's simplify Equation (1) by considering a beam reach, for which $\gamma = 90$ degrees. Then

$$X^4 - a^2(C_L - C_DX)^2(X^2 + 1) = 0 \quad (5)$$

C_L and C_D do not vary over a very wide range for conventional soft sails and we can take the modest variation of these coefficients into account by use of the following empirical formulae:

$$C_L = [1 + 0.0203\,(A_SL/W)] / 0.736 \quad (6)$$

$$C_D = [1 - 0.0335\,(A_SL/W)] / 2.11 \quad (7)$$

Using Equations (4), (6), and (7), we solve Equation (5) numerically for V_B/V_T as a function of A_SL/W. The results are given in Figure 1 and Table 1.

The older generation of ocean racing multihulls such as *Manureva*, *Spirit of America*, and *Rogue Wave* had values of A_SL/W between 5 and 6 and were capable of speeds on a beam reach about equal to the wind speed. More recent boats such as *Colt Cars* and *Brittany Ferries* have A_SL/W values between 8 and 9 and are consequently capable of speeds on a beam reach 40% greater than wind speed.

Now let's turn our attention to the other of AYRS #120's master equations – the expression for maximum boat speed as limited by righting moment, the heavy-air equation:

$$V_{B\,MAX} = \left\{ \left| \frac{1}{\alpha}\,\frac{bL}{h}\,\frac{[C_L\sin\gamma - C_D(X + \cos\gamma)]}{[C_L(X + \cos\gamma) + C_D\sin\gamma]} \right| \right\}^{1/2} \quad (8)$$

where b is the horizontal distance between the center of gravity and the center of buoyancy at maximum righting moment (half the overall beam on a catamaran or trimaran; somewhat more or less than half the beam on a proa), and h is the vertical distance between the center of effort of the rig and the center of effort of the board or keel.

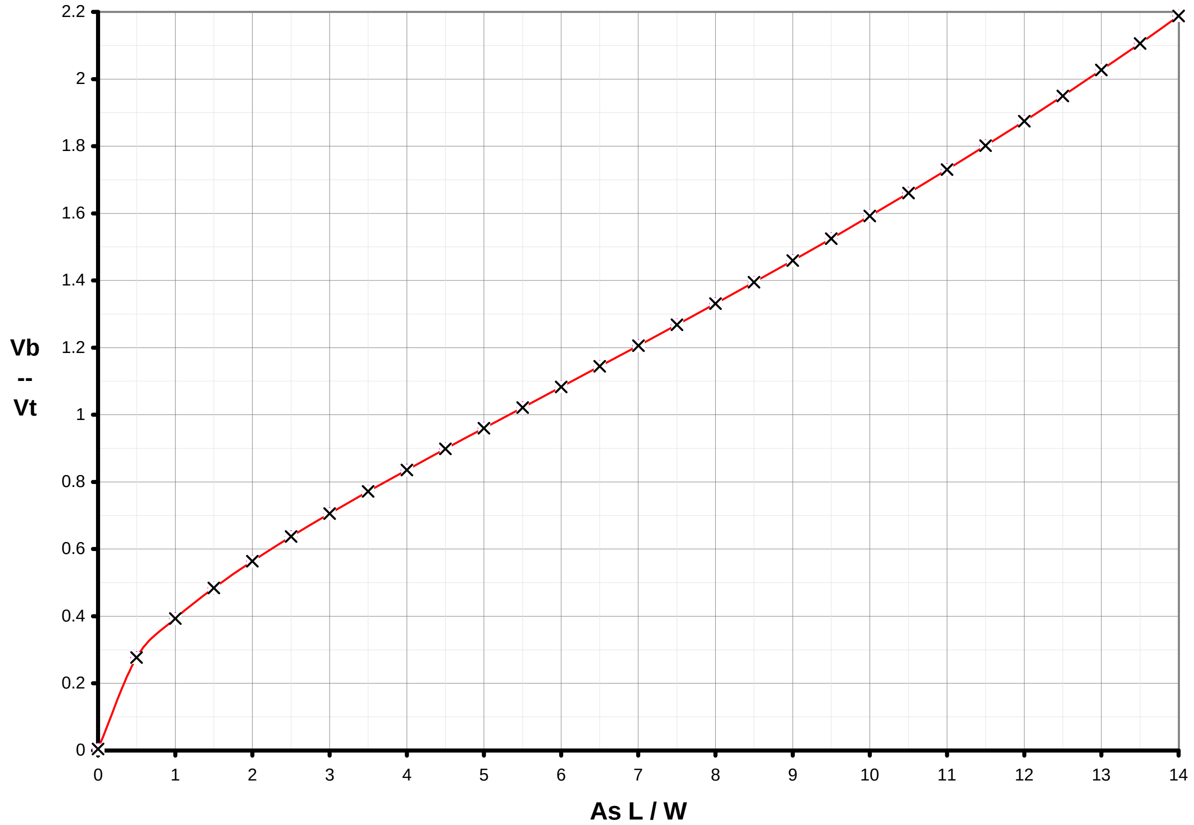


Figure 1: VB/VT *(= X) as a function of* ASL/W *for a beam reach, γ = 90 deg.*

ASL/W	VB/VT	VT=6	8	10	12	15	20	25	30	35	40
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.50	0.28	1.50	2.00	2.50	3.00	3.80	5.00	6.30	7.50	8.80	10.00
1.00	0.39	2.36	3.14	3.93	4.71	5.89	7.85	9.82	11.78	13.75	15.71
1.50	0.48	2.91	3.87	4.84	5.81	7.26	9.68	12.10	14.53	16.95	19.37
2.00	0.56	3.38	4.51	5.64	6.77	8.46	11.28	14.10	16.92	19.74	22.56
2.50	0.64	3.82	5.10	6.37	7.65	9.56	12.74	15.93	19.12	22.30	25.49
3.00	0.71	4.24	5.65	7.06	8.47	10.59	14.12	17.65	21.18	24.71	28.24
3.50	0.77	4.63	6.17	7.72	9.26	11.58	15.44	19.30	23.16	27.01	30.87
4.00	0.84	5.01	6.69	8.36	10.03	12.54	16.72	20.89	25.07	29.25	33.43
4.50	0.90	5.39	7.19	8.98	10.78	13.48	17.97	22.46	26.95	31.44	35.94
5.00	0.96	5.76	7.68	9.60	11.52	14.40	19.20	24.01	28.81	33.61	38.41
5.50	1.02	6.13	8.17	10.22	12.26	15.32	20.43	25.54	30.65	35.76	40.86
6.00	1.08	6.50	8.66	10.83	12.99	16.24	21.66	27.07	32.48	37.90	
6.50	1.14	6.87	9.15	11.44	13.73	17.16	22.88	28.60	34.33	40.05	
7.00	1.21	7.24	9.65	12.06	14.47	18.09	24.12	30.15	36.18		
7.50	1.27	7.61	10.14	12.68	15.22	19.02	25.36	31.70	38.04		
8.00	1.33	7.99	10.65	13.31	15.97	19.96	26.62	33.27	39.93		
8.50	1.39	8.37	11.16	13.95	16.73	20.92	27.89	34.86			
9.00	1.46	8.76	11.67	14.59	17.51	21.89	29.18	36.48			
9.50	1.52	9.15	12.20	15.25	18.30	22.87	30.50	38.12			
10.00	1.59	9.55	12.74	15.92	19.10	23.88	31.84	39.80			

Table 1: VB *as a function of* VT *and* ASL/W

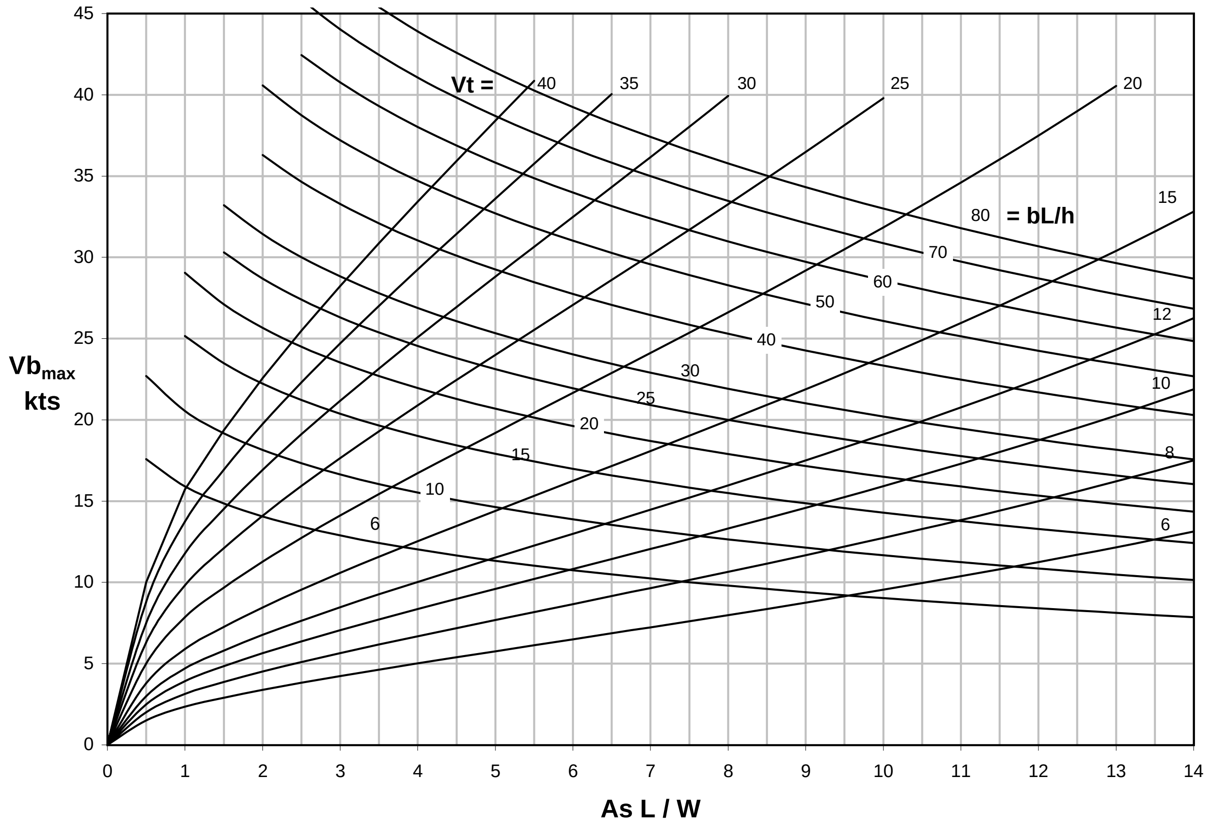


Figure 2: Curves of $V_{B_{max}}$ *plotted as a function of* AsL/W *for constant* bL/h, *and of* V_B *as a function of* AsL/W *at constant* V_T*; all for a beam reach,* γ *= 90 deg.*

AsL/W	bL/h = 6	10	15	20	25	30	40	50	60	70	80
0.50	17.58	22.70									
1.00	15.91	20.54	25.16	29.05							
1.50	14.85	19.17	23.48	27.11	30.31	33.20					
2.00	14.06	18.15	22.23	25.66	28.69	31.43	36.29	40.58			
2.50	13.42	17.33	21.22	24.51	27.40	30.01	34.66	38.75	42.44	45.84	
3.00	12.89	16.64	20.38	23.53	26.31	28.82	33.28	37.21	40.76	44.03	
3.50	12.43	16.05	19.65	22.69	25.37	27.79	32.09	35.88	39.31	42.46	45.39
4.00	12.02	15.52	19.01	21.95	24.54	26.89	31.05	34.71	38.02	41.07	43.91
4.50	11.66	15.05	18.44	21.29	23.80	26.07	30.11	33.66	36.87	39.83	42.58
5.00	11.33	14.63	17.91	20.69	23.13	25.33	29.25	32.71	35.83	38.70	41.37
5.50	11.03	14.24	17.44	20.13	22.51	24.66	28.47	31.83	34.87	37.66	40.27
6.00	10.75	13.87	16.99	19.62	21.94	24.03	27.75	31.02	33.99	36.71	39.24
6.50	10.49	13.54	16.58	19.15	21.41	23.45	27.08	30.27	33.16	35.82	38.29
7.00	10.24	13.22	16.20	18.70	20.91	22.90	26.45	29.57	32.39	34.99	37.40
7.50	10.01	12.93	15.83	18.28	20.44	22.39	25.86	28.91	31.67	34.20	36.57
8.00	9.80	12.65	15.49	17.89	20.00	21.91	25.30	28.28	30.98	33.47	35.78
8.50	9.59	12.39	15.17	17.52	19.58	21.45	24.77	27.69	30.34	32.77	35.03
9.00	9.40	12.13	14.86	17.16	19.19	21.02	24.27	27.13	29.72	32.11	34.32
9.50	9.21	11.90	14.57	16.82	18.81	20.60	23.79	26.60	29.14	31.47	33.65
10.00	9.04	11.67	14.29	16.50	18.45	20.21	23.34	26.09	28.58	30.87	33.00

Table 2: $V_{B_{max}}$ *for a beam reach (*γ *= 90 deg) as a function of* AsL/W *and* bL/h

For this equation, we will use a conversion factor $K = 1.69$ ft/sec/knot so as to make VB_{MAX} come out in units of knots. Again, we will choose to specialize Equation (8) for a beam reach, $\gamma = 90$ degrees, for which we find

$$VB_{MAX} = \frac{1}{K}\left\{\left|\frac{1}{\alpha}\;\frac{bL}{h}\;\frac{[\,C_L - C_D X\,]}{[\,C_L X + C_D\,]}\right|\right\}^{1/2} \text{............} (9)$$

Using the results of our solution of Equation (5), we calculate VB_{MAX} from Equation (9). These results are shown in Figure 2 and Table 2. In this Figure, we have plotted curves of VB for constant true wind speed, VT (VB = VT.X), and curves of VB_{MAX} for constant bL/h. Here is how we use it.

Suppose we have a boat like *3 Cheers*, for which $A_S L/W$ is about 5 and bL/h is about 25. We start at $A_S L/W = 5$ on the lower horizontal scale and go straight up to intersect the curve for bL/h = 25. We then trace horizontally left to find VB_{MAX}=23.1 kts. The point of intersection with the bL/h = 25 curve is very near the curve for $V_T = 25$ knots, which is the true wind required to attain this speed on a beam reach at maximum righting moment. The two figures can also be used to find the values of A_S, L, W, b, and h required in designing a boat to attain certain performance criteria in light and heavy air.

This model is certainly not highly refined, but it is quite accurate owing to the following properties of multihulls: First, the hulls are slender enough so that the expression aWV_B^2/L is an adequate description of hydrodynamic drag [wave drag amplitude is proportional to $(\text{beam/length})^2$ and can be ignored]. Second, heeling can be neglected.

As we have noted, in order to design a boat for a specific performance with a fair expectation that the boat will achieve it, you need only specify A_S, L, W, b, and h. The sail area A_S is proportional to L^2, and the displacement, W, scales approximately as L^3, so $A_S L/W$ is, to a first approximation, independent of the size of the boat. On the other hand, bL/h is proportional to L, and since VB_{MAX} scales with the square root of bL/h, we should expect the maximum speed potential of a boat to go up roughly as $L^{1/2}$. There is also, of course, the fact that a large boat is better able to handle the sea state that goes along with good, stiff sailing winds.

These conclusions are only valid for boats large enough so that crew shifts have no effect, unless, of course, you calculate W and b taking the crew weight and disposition into account.

In designing a catamaran or trimaran for fast cruising, I would shoot for $A_S L/W$ of about 5. The bL/h should be about 0.42L for a catamaran and perhaps 0.5L for a trimaran. For a competitive racing machine, $A_S L/W$ should not be less than 9, with $bL/h \geq 0.47L$ for a catamaran or 0.55L for a trimaran. This should be just about the state-of-the-art for present materials technology. For a large racing proa, you might contemplate $A_S L/W$ of 10.0 to 10.5, with bL/h of about 0.65L.

We can also specify an overall figure of merit. We know that $A_S L/W$, more or less independent of L, constitutes a measure of light-air performance. The quantity bL/h, which scales linearly with L, denotes performance at the limit of righting moment. An all around good boat should combine both qualities in a balanced measure. Thus we propose as a figure of merit $A_S bL/(Wh)$, which is independent of the size of the boat. Using the figures arrived at above, we see that for boats with interesting performance, this number should not be less than 2.0, and for a state-of-the-art racer, the number might run as high as 6 or 7.

Note on units —

The units used to calculate these values of AsL/W are American – feet, ft², and pounds-weight. People working in metric units (metres, m², and kg) will need to multiply the (metric) values they obtain by about 15.6 before comparing them with the values quoted above. Of course, if everyone multiplied their values by the weight/volume of water, the results would be non-dimensional, if much larger numerically — Ed.

Hull Shape

Tom Speer

My approach to defining the hull geometry starts with the overall characteristics, like the length, displacement, center of buoyancy, and prismatic coefficient. These are the most important parameters in defining the hull's carrying capacity and its wave resistance.

The underwater cross section shape is defined by non-dimension shape parameters that control the beam/depth ratio, the angle of the sides near the waterline, and the slackness of the bilge. I vary these parameters smoothly along the length of the hull to produce a fair shape. The wetted area is the biggest influence on the hull's low speed resistance, and this is largely determined by the cross sectional shape. The wave drag is also influenced by the cross sectional shape, but this is not as strong an influence as the manner in which the area of each cross section changes along the length of the hull - the cross sectional area distribution.

The underwater hull shape is determined by combining the section shape with the cross sectional area distribution. I have used Fourier series to define how the area changes along the length of the hull. Once I have the cross sectional area distribution, I size the cross section shapes at each station to match the desired cross sectional area at that station.

This approach has the advantage that I can change the section shapes without affecting the overall hull characteristics. It also makes it easy to shrink or stretch the hull while maintaining a similar shape.

Cross Sectional Area Distribution

I've chosen to use some simple Fourier series for defining the cross sectional area distribution because the Fourier series produce a smooth, pleasing variation of the areas, and because they can be integrated analytically to get the overall characteristics. Similar functions have been used for tank test models that are reported in the literature, so I can use this information to help estimate the hull's resistance. It also meets the criteria above, since the free parameters are the length of the waterline, displacement, center of buoyancy, and prismatic coefficient. The relationships are:

$$X = \tfrac{1}{2} L_{wl}\left[1 + \mathrm{Cos}(\xi) + 2 l_{cb}(1 - \mathrm{Cos}(2\xi))\right]$$

where $0 \le \xi \le \pi$ and

$$S = \frac{V}{L_{wl}}\left[\frac{4}{\pi}\sin\xi + \left[\frac{2}{\pi} - \frac{5}{8Cp}\right]\sin(3\xi) + \left[\frac{-2}{\pi} + \frac{3}{8Cp}\right]\sin(5\xi)\right]$$

As ξ varies from π to 0, it sweeps the sections from bow to stern. When $\xi = \pi/2$, the cross sectional area is at its maximum. This section will be located twice as far aft of midships as is the center of buoyancy

This constant-length, constant-volume approach also leads to a different interpretation for the prismatic coefficient, Cp. Traditionally, Cp has been considered a measure of how full the ends of the hull are. Cp is defined as:

$$Cp = \frac{V}{S_x \cdot L}$$

But when volume and length are kept constant, the choice of Cp controls the size of the maximum cross sectional area:

$$S_x = \frac{V}{Cp \cdot L}$$

Volume and length are largely determined by the purpose of the boat and its load carrying capacity. The choice of Cp, because of its effect on the maximum cross sectional area, largely determines the maximum beam.

This is why there is an optimum Cp for different design speeds (Froude numbers). A larger Cp will result in blunter ends, which would be expected to cause more wave drag. However, it also narrows the beam, improving the length-to-beam ratio, which lowers wave drag. For Cp's below the optimum, the hull is too beamy, and for Cp's above the optimum, the ends are not fine enough.

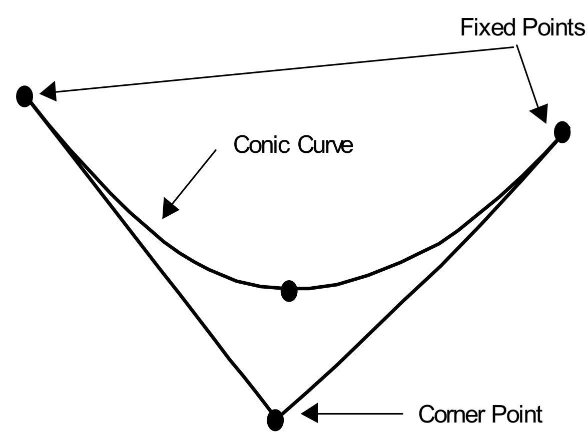
Values of optimum Cp for monohulls can be found in "Principles of Yacht Design". The values should generally lie between 0.5 and 0.6, with higher values used for higher design speeds. For these functions, values of Cp less than $\pi/7$ (0.45) will result in non-physical shapes, with negative areas near the ends.

Here's a bit of trivia from the strange world department: if you set Cp to $3\pi/16$ (0.589), l_{cb} to zero, and use circular cross sections, the resulting shape is known as a Sears-Haack body. This is the shape that produces the minimum wave drag in supersonic flight. Coincidentally, this Cp also produces the minimum drag for a boat that is operated at hull speed (Froude number = 0.40)!

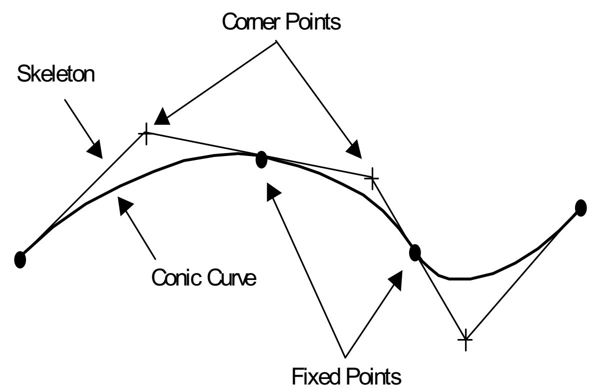
Conic Section Lofting

Now that I have the cross sectional area distribution, the next job is to define the shapes of the cross sections. One way to do this is by piecing together curves that are parts of ellipses, parabolas, and hyperbolas. If one has two intersecting line segments forming a "V", one can find a conic section that has these properties:

a) It passes through the end points of the V.
b) It is tangent to the lines at the end points.
c) It can be made to pass through any third point which is located inside the area enclosed by the "V".



By joining together a number of such curves, one can approximate nearly any shape. The points where the curves join together are fixed in space, and straight lines are drawn through these points to form an outer skeleton. The points where the lines through the fixed points intersect are called corner points. The degree of curvature between the fixed points is controlled by either defining a third fixed point inside the V, or by a parameter that represents how much the curve is attracted to the corner point.



This approach to lofting is very intuitive, since the shape can be sketched out using the straight line skeleton. The curves are smooth and continuous, and it is easy to see what the effect will be of changing any of the defining points. Although I will be presenting the algebraic equations that define these curves, one doesn't need a computer to draw them. They can be quickly created using just a compass and straight edge. For more details, see Dan Raymer's "Aircraft Design: A Conceptual Approach".

More aeronautical trivia: the legendary P-51 Mustang was one of the first aircraft to be designed using conic lofting. Part of its remarkable performance has been attributed to the fairness of the resulting lines.

Analytically, the conic curve is defined by six coefficients. The parameter, t, is used to sweep the curve from one end to the other. When t = -1 or +1, the curve is at the end points. When t = 0, the curve is at the fixed interior point. This point is defined by the parameter, ρ, which is the relative distance from the corner point to the midpoint between the fixed ends. When $\rho = 0$, the curve goes through the corner point, and has a sharp break. When $\rho = 1$, the curve is a straight line between the end points. Separate curves are used in all three coordinate directions (X, Y, Z) so that there is no problem with multiple values. The basic relationships are:

Equation for the curve:

$$0 = c_1x^2 + c_2x.t + c_3t^2 + c_4x + c_5t + c_6$$

Midpoint between the ends:

$$x4 = \frac{(x1 + x3)}{2}$$

The third fixed point in the "throat":

$$x_5 = \rho(x_4 - x_2) + x_2$$

$$x_5 = \rho/2\ (x_1 + x_3) + (1 - \rho)x_2$$

Taking the derivative with respect to t:

$$0 = c_1\left(2x\,\tfrac{dx}{dt}\right) + c_2\left(x + t\,\tfrac{dx}{dt}\right) + 2c_3 t + c_4\left(\tfrac{dx}{dt}\right) + c_5$$

By applying the conditions at t = -1, 0, 1, five equations result that can be used to solve for the coefficients:

$$\text{when } t = -1,\ x = x_1, \text{ and } x' = x_2 - x_1$$
$$\text{when } t = 0,\ x = x_5$$
$$\text{when } t = 1,\ x = x_3,\ x' = x_3 - x_2$$
$$0 = c_1 x_1^2 - c_2 x_1 + c_3 + c_4 x_1 - c_5 + c_6$$
$$0 = c_1 x_5^2 + c_4 x^5 + c_6$$
$$0 = c_1 x_3^2 + c_2 x_3 + c_3 + c_4 x_3 + c_5 + c_6$$
$$0 = 2c_1 x_1(x_2 - x_1) + c_2(2x_1 - x_2) - 2c_3 + c_4(x_2 - x_1) + c_5$$
$$0 = 2c_1 x_3(x_3 - x_2) + c_2(2x_3 - x_2) + 2c_3 + c_4(x_3 - x_2) + c_5$$

Some special cases have to be considered. If $x_5 = 0$ then $c_6 = 0$, and $c_5 = 1$. Otherwise, $c_6 = 1$.

Putting the equations in matrix form:

$$\begin{bmatrix} -1 \\ -1 \\ -1 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} x_1^2 & -x_1 & 1 & x_1 & -1 \\ x_5^2 & 0 & 0 & x_5 & 0 \\ x_3^2 & x_3 & 1 & x_3 & 1 \\ 2x_1(x_2 - x_1) & 2x_1 - x_2 & -2 & x_2 - x_1 & 1 \\ 2x_3(x_3 - x_2) & 2x_3 - x_2 & 2 & x_3 - x_2 & 1 \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \\ c_5 \end{bmatrix}$$

$$c_6 = 1$$

If $x_5 = 0$:

$$\begin{bmatrix} 1 \\ -1 \\ -1 \\ -1 \end{bmatrix} = \begin{bmatrix} x_1^2 & -x_1 & 1 & x_1 \\ x_3^2 & x_3 & 1 & x_3 \\ 2x_1(x_2 - x_1) & 2x_1 - x_2 & -2 & x_2 - x_1 \\ 2x_3(x_3 - x_2) & 2x_3 - x_2 & 2 & x_3 - x_2 \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \end{bmatrix}$$

$$c_5 = 1 \quad \text{and } c_6 = 0$$

These can be solved using standard numerical methods, such as Gauss-Jordan elimination.

Once the coefficients are in hand, other points on the curve can be obtained, given values for t. If $c_1 = 0$, then the solution is straightforward:

$$x = \frac{-(-c_3 t^2 - c_5 t - c_6)}{(-c_2 t - c_4)}$$

If, in addition to $c_1 = 0$, $(c_2)t = -c_4$, there is no solution.

If c1 is not zero, there are two solutions:

$$x = \left|\begin{array}{l} \dfrac{-1}{2c_1}\left[c_2 t + c_4 + \sqrt{(c_2 t + c_4)^2 - 4c_1(t^2 c_3 + t c_5 + c_6)}\right] \\[2ex] \dfrac{-1}{2c_1}\left[c_2 t + c_4 - \sqrt{(c_2 t + c_4)^2 - 4c_1(t^2 c_3 + t c_5 + c_6)}\right] \end{array}\right.$$

Which solution is correct is somewhat problematic. I compute both, and pick the one that lies inside the "V" formed by the defining points. This means that the coefficients alone are not sufficient to evaluate the curve - one must also have the original defining points. This means that I have to store nine or ten quantities for each segment: the two endpoints, corner point, six coefficients, and (optionally) the slackness parameter, ρ. And this has to be repeated for both of the two spatial dimensions, Y and Z. This bulkiness is probably the biggest drawback to the method.

In addition to the case of $c_1 = 0$, one also has to be careful of the case where

$$(c_2 t + c_4)^2 - 4c_1(c_3 t^2 + c_5 t + c_6) < 0$$

This also means there is no solution, and the coefficients are probably invalid.

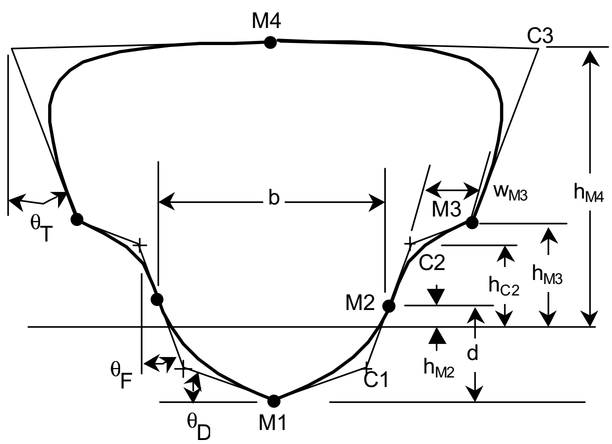
Cross Section Shapes

The actual hull form is finally determined through the choice of section shape. I have used the conic section lofting to define a generic shape that can be adapted to different hull forms by simply varying the parameters. One segment is used to define the underwater shape, and three more segments define the shape of the topsides and deck. Dimensionless parameters are used to define the underwater portion, which makes it easier to size it to the cross sectional area distribution. The topsides are sized relative to the underwater portion, but the vertical distances are kept fixed.

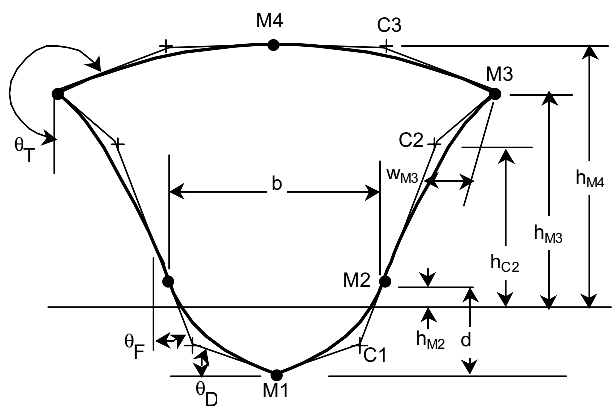
Twelve parameters define the section shape. The first five, along with the cross sectional area, define the underwater portion:

BDR	beam/depth ratio = b/d
$\tan(\theta_D)$	tangent of deadrise angle
ρ_1	bilge slackness parameter
h_{M2}	height of moldline M2 above the design waterline
$\tan(\theta_F)$	slope of the hull near the waterline.

Bell Shape



Flared Shape



BDR is the most important parameter, as it controls the depth of the hull and has the most effect on the wetted area. A semicircle has a beam/depth ratio of 2.0, so BDR should be approximately two if minimum wetted area is the object. Decreasing BDR toward the bow will reduce the amount of rocker that would otherwise result from the shape of the cross sectional area distribution, and will make the bow finer. Increasing BDR toward the stern will give broader, flatter sections, but will also steepen the curve of the buttlines.

The deadrise angle controls how much "V" there is to the bottom. Setting the deadrise to zero results in a round bottom. The parameter ρ_1 determines how hard the bilge is. A value of zero results in a sharp chine at C1, and a value of 1 results in a straight line between M1 and M2. Values in the neighborhood of 0.3 to 0.5 result in smoothly rounded shapes.

The mold line M2 is intended to shape the design waterline. Raising it above the waterline maybe necessary to improve the numerical characteristics at the ends, where the cross sectional area goes to zero. It may also be desirable to raise the M2 moldline for hulls with overhangs. The slope, $\tan(\theta_F)$, at M2 is defined relative to vertical. A zero value results in a vertical exit of the topsides from the water.

I originally structured the shape of the topsides to form a bell shape, similar to that used in Shuttleworth catamaran designs. However, this same structure can represent the flared shapes of many Newick designs, as well as a conventional hull shape, with or without tumblehome. The parameters defining the topsides are:

h_{C2} height of C2 above design waterline
r_2 curvature parameter for segment M2-M3
h_{M3} height of M3 above design waterline
r_3 curvature parameter for segment M3-M4
h_{M4} height of M4 above design waterline
w_{M3} width of hull flare, relative to the extended slope at M2
$\tan(q_T)$ slope of topsides from vertical

w_{M3} controls how much the topsides below M3 deviate from a straight line. Positive values will push M3 outboard, forming a knuckle or flare. Negative values will produce tumblehome. A zero value will result in a straight line between M2 and M3, regardless of the slope or the position of C2. h_{C2} will generally be less than or equal to h_{M3}. If they are equal, the slope of the hull at the knuckle will be parallel to the waterline.

The moldline M3 forms a sharp chine. In the bell shaped section, with its rounded topsides, M_3 locates the knuckle. On the other shapes, M_3 is the shear. How this line varies along the hull has a major influence on the appearance of the boat. The final mold line, M4, determines the height of the cabin, and must be designed in concert with M3.

A zero value for $\tan(\theta_T)$ will result in a vertical topside starting at the knuckle in the bell shape. A comparatively large negative value is required for the more conventional shapes. In the latter two cases, this parameter will control the slope of the deck at the hull/deck joint.

The degree of curvature in the topsides is controlled by the parameters ρ_2 and ρ_3. In most cases, the shape is not very sensitive to these parameters, due to the shallow angles of the skeleton at the corner points. For the bell shape, however, ρ_3 has a major effect on the shape. A small value will result in drawing the hull toward C3, and this can be used to create a straighter topsides and a more conventional, sharp edged, shear line.

Adjusting Section Shapes to the Cross Sectional Area

Finally, I put all this together and determine the width and remaining dimensions of the section shape. This is an iterative process, but it converges very rapidly. It uses the numerical integration to be described in a later article on Hydrostatics. So I will skip over the mechanics of calculating the underwater cross sectional area numerically, and cover how the shape is adjusted to match.

The first step is to get an approximate value for the section dimensions. The skeleton of the underwater shape is very useful here, since it is easy to calculate the area inside the skeleton, and this allows me to calculate the beam as a function of the area. C1 is located at the intersection of the skeleton lines through M1 and M2, and the coordinates of M2 can also be written in terms of the hull depth::

$$Y_{C1} = \frac{1}{2}\cdot d\cdot\frac{\left(-BDR + 2\cdot\tan\left(\theta_F\right)\right)}{\left(-1 + \tan\left(\theta_F\right)\cdot\tan\left(\theta_D\right)\right)}$$

$$Z_{C1} = \left[1 - \frac{1}{2}\cdot\tan\left(\theta_D\right)\cdot\frac{\left(-BDR + 2\cdot\tan\left(\theta_F\right)\right)}{\left(-1 + \tan\left(\theta_F\right)\cdot\tan\left(\theta_D\right)\right)}\right]\cdot d$$

$$Y_{M2}=BDR^{d}/_{2}$$

$$Z_{M2}=-h_{M2}$$

I use the area of the skeleton to get the first approximation of the cross sectional area, S_0:

$$S_0 = \frac{1}{8}\cdot\frac{\left(-\tan\left(\theta_D\right)\cdot BDR^2 - 4\cdot\tan\left(\theta_F\right) + 4\cdot BDR\right)}{\left(1 - \tan\left(\theta_F\right)\cdot\tan\left(\theta_D\right)\right)}\cdot d_0^{\,2} \ldots$$
$$+ -\frac{1}{2}\cdot BDR\cdot h_{M2}\cdot d_0 + \frac{1}{2}\cdot h_{M2}\cdot\tan\left(\theta_F\right)$$

This is solved for the first guess at the hull depth, d_0 using the quadratic formula (only the positive branch is of interest). Once a definite value for the depth is known, all the other dimensions of the section can be calculated, including the offsets.

The next step is to numerically integrate the underwater area of the section, S_0, using the first guess at the offsets. This will probably be a little smaller than the design area, S. The area scales as d^2 if h_{M2} is small, so final step is to obtain the revised estimate for d, d_1:

$$d_1 = d_0\sqrt{\frac{S}{S_0}}$$

The section dimensions are recalculated based on d_1. The last two steps may be repeated until the design and actual areas match as closely as desired.

Tables of Offsets

The preceeding relationships are sufficient for completely defining the shape of the hull's canoe body. However, if ξ is varied in a regular manner, the spacing of the sections will not be uniform. The stations will actually be very well placed for numerical purposes, with more stations in locations, such as the bow and stern, where the lines are changing rapidly. However, the typical convention is to have stations distributed evenly, forming ten intervals between the perpendiculars at the ends of the design waterline.

If the longitudinal locations of the stations are known, the following relationships can be used to find ξ so that the cross sectional area can be computed for that location.

If l_{cb} is not zero,

$$x = a\cos\left[\frac{1}{8.l_{cb}}\left\{1-\sqrt{1-32.l_{cb}\frac{x}{L_{wl}}+16.l_{cb}+64.l_{cb}^{\,2}}\right\}\right]$$

Otherwise,

$$\xi = a\cos\left(2\cdot\frac{X}{Lwl} - 1\right)$$

A similar situation exists with respect to creating waterlines and buttlines at regular intervals. Computing the value for t, given an x, is similar to solving for x, given t. The same equations can be used, if t and x are exchanged, along with the corresponding coefficients (c_1 for c_3 and c_4 for c_5).

I have chosen to evaluate the shape at even values of t, however, to create an internal table of offsets. I generate waterlines, buttlines, and diagonals by interpolating this internal table's intersection with an arbitrary cutting plane. This procedure is necessary in any event to compute the waterline plane for arbitrary pitch and roll attitudes, so it is convenient to use it to generate the hull's lines.

Appendices

List of Symbols

b	hull beam at M2
BDR	beam/depth ratio = b/d
C1	intersection of deadrise and slope through M2
C2	corner point defining flare of the topsides
C3	corner point defining deck crown
$c_1 \ldots c_6$	conic curve fit coefficients
Cp	prismatic coefficient
d	hull depth from M2
d_0, d_1	approximations to d
h_{C2}	height of C2 above design waterline
h_{M2}	height of M2 above design waterline
h_{M3}	height of M3 above design waterline
h_{M4}	height of M4 above design waterline
l_{cb}	position of center of buoyancy aft of midships, as a fraction of waterline length
L_{wl}	length of the waterline (ft or m)
M1	bottom centerline
M2,	mold line near design waterline
M3	mold line forming chine or shear
M4	deck centerline
S	cross sectional area (ft^2 or m^2)
S_0, S_1	approximations to S
S_{wet}	wetted area (ft^2 or m^2)
S_x	maximum cross sectional area (ft^2 or m^2)
t	independent parameter
V	volume (ft^3 or m^3)
w_{M3}	width of hull flare, measured from extension of slope at M2
X	distance in longitudinal coordinate direction, positive aft (ft or m)
x	generic spatial distance
x_1, x_3	conic curve fixed points
x_2	conic curve corner point
x_4	midpoint of line connecting conic curve fixed points
x_5	interior fixed point of conic curve
Y	distance in lateral coordinate direction, positive starboard (ft or m)
Z	distance in vertical coordinate direction, positive up (ft or m)
θ_D	deadrise angle (radians or degrees)
θ_F	flam (radians or degrees)
θ_T	topsides angle (radians or degrees)
ξ	independent parameter (radians)
ρ	conic curve parameter;. fluid density (slug/ft^3 or kg/m^3)
ρ_1	bilge slackness parameter
ρ_2	curvature parameter for segment M2-M3
ρ_3	curvature parameter for segment M3-M4

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PRACTICAL PROAS

Joseph Norwood

I have been interested in proas for years — thinking about them and writing about them. Last year I decided that it was high time that I built one and put my money (and a good deal of work) where my mouth was. It would be a daysailer, but large enough such that the experience gained would have general application to proas in all sizes. I settled on a design (cartoon for a design, actually) published by Phil Bolger in the December-January 1990 issue of Small Boat Journal. I scaled Bolger's design up by about five percent, worked out the details, scantlings, etc, and set to work. *Falcon* was launched in June 2000, 20 feet, 6 inches overall length, 12 foot beam, with 109 square feet of sail. After a summer of sailing and minor modifications, I now feel that I probably have the best proa in the world. That extravagant claim needs some elaboration and justification.

First of all, *Falcon* is a Pacific proa, which is to say its outrigger is to windward as opposed to the *Cheers* or Atlantic type whose outrigger is to leeward. Let me state briefly why I think that the Pacific type is superior.

In the Atlantic proa, righting moment is supplied by the buoyancy of the leeward outrigger, which must therefore be capable of supporting the entire weight of the boat. Thus the hull configuration must effectively be that of a catamaran with the rig and accommodation on the windward hull. Secondly, there is not an adequate shroud angle and so the mast or masts must be free-standing, which adds to the weight and windage. Thirdly, there is a balance problem. As the wind pipes up and the lee hull is driven deeper into the water, the center of hydrodynamic drag moves to leeward, while the aerodynamic driving force stays to windward. In order to compensate this unavoidable growth in the yawing torque, you must either have two longitudinally separated boards that can be independently deployed or withdrawn as needed to adjust the location of the center of lateral resistance, or you must have a divided rig on two masts. *Cheers* had both. Finally, and most seriously, all of the windage is on the weather hull, and so the Atlantic proa is unstable to yawing perturbations. Left to itself, an Atlantic proa will turn itself about and put its outrigger to windward and capsize aback. *Cheers* and most of its clones experienced such a capsize.

With the Pacific proa, righting moment is provided by the weight of the windward outrigger and, in the daysailing sizes, by whatever crew members are sent scampering out to windward to augment this weight. Thus the outrigger can be small (60 percent of the length of the lee hull in *Falcon)* as it is not called upon to provide more buoyancy than is needed to support a crew member who boards the boat from the windward side. Secondly, there is a generous shroud angle; the mast and outrigger can hold each other up through the shrouds, hence the mast and cross-beams can both be lighter than is the case with the Atlantic proa. Thirdly, as the speed of a Pacific proa increases and the windward outrigger rises from the water, all of the forces move into a single vertical plane and the yawing torques vanish. Finally, all of the windage in the Pacific proa is naturally to leeward, and so the boat is stable hands-off.

I knew all this before I built *Falcon.* The lessons that *Falcon* taught me have to do with the rig and the rudder/boards system.

The usual rig on a proa is a boomed leg-o'-mutton rig, or some variation thereof, sometimes with a roller-furling headsail on either end. Props are symmetric longitudinally and asymmetric laterally. The aforementioned rig is, however, symmetric laterally and asymmetric longitudinally. Hence the rig must be turned around 180 degrees and one headsail must be furled and the other unfurled in order to change ends (shunt). This is a lot of time-consuming work and calls for a complex system of sheets. How much simpler it would be if the rig was symmetric longitudinally (interchangeable luff and leach) and asymmetric laterally. *Falcon* has such a rig, a full-battened, semi-elliptic squaresail. I can see our late founder, John Morwood, who strongly advocated such a rig, smiling. The battens and boom are laminated into a permanent curve to give the sail a dedicated leeward and windward side. Sheet attachments are 20 percent from each end of the boom, which gives a semi-balanced rig, still capable of reliable weathercocking. The sheets double as downhauls (luff lines). The shunting maneuver entails only hardening down the former sheet and freeing the former downhaul in order to change luff to leach and vice versa. An adjustable jackstay along each of the two pivot axes of the sail prevents the sail from kiting as it is being raised or lowered (the sail is attached to the mast only at the halyard) and aids in adjusting the vertical curve of the rig.

What about rudders and boards? These are always such a problem in proas. Raise one, lower the other; unfasten the whipstaff linkage from one and fasten it to the other. By the time you get the usual proa moving in the other direction, you have probably drifted a good long way to leeward. Not so on *Falcon,* which has two permanently deployed rudder/boards, balanced so that the forward one is used for steering and the tiller on the aft one is locked down for the board to provide leeway resistance. Changing ends is as simple as placing the locking pin in one tiller and removing it from the other tiller. The entire act of shunting takes *less than ten seconds.* Is it any wonder that I claim to sail the best proa in the world?

Helm balance is neutral under most conditions. *Falcon* will sail herself for miles, hands off. If you nudge the tiller to introduce a yawing perturbation, *Falcon* will come right back onto course. As the outrigger rises from the water, a very gentle lee helm arises, which is perfectly suited to the bow steering.

What about scaling this configuration to larger sizes? At a hull length of 25 to 40 feet, the outrigger would have sufficient buoyancy to support a windward cockpit. Being this far back from the sail would be a big advantage. I often get a crick in my neck looking up *Falcon's* mast at the wind indicator. In such a 'weekender' size, cozy overnight accommodation can be established in the leeward hull and/or on the leeward end of the deck connecting hull to outrigger. This size can also accommodate a small retractable outboard.

For a real ocean cruiser, I would want to put the accommodation, as well as the cockpit, on the outrigger. This has the advantage of putting most of the weight as far to windward as possible, thus maximizing the righting arm (which is what proas are all about). The windward hull (outrigger) should be kept as aerodynamically clean as possible in order to preserve the yaw stability discussed earlier. All airfoils (sails) and hydrofoils (rudder/boards) will be on the long leeward hull. The facility to take on water ballast in the aft end of the outrigger may be incorporated so as to give the option of reefing and/or ballasting down in heavy air. But I am down to details now and I have really said all that I set out to say.

If you want to inquire about the availability of plans for a *Falcon-class* proa, get in touch with Phil Bolger at P.O. Box 1209, Gloucester, MA 01930, USA. I might also mention that the original Small Boat Journal article in which the concept first appeared, was reprinted in Phil's book, *Boats With An Open Mind* (McGraw-Hill, 1994). Phil has introduced the critical design innovation needed to move proas into the mainstream and make them the multihull of choice. He has my profound thanks.

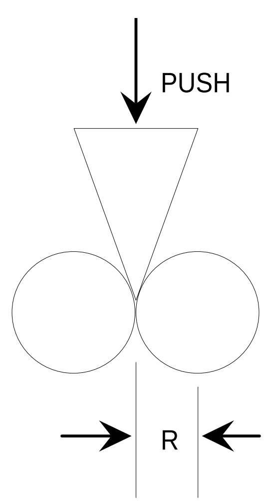
Joseph Norwood is a mathematician and author of "21st Century Multihulls" (AYRS Pub 120)

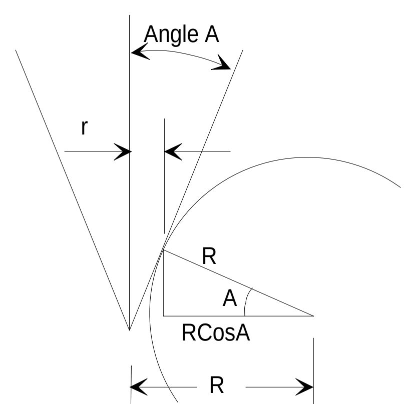
Fid Physics, or Phyd Fisics,

or More Than You Ever Wanted To Know About A Fid

Frank Bailey

The fid, as we all know, is a conical shaped piece of material, usually made of hard wood, that is used to force open a tight knot. Sometimes, on especially tight knots, it is hammered a bit into the knot. This article was written as a result of trying to figure out if there is an optimum angle, that is, an angle from the central axis to the edge of the cone, or the half angle, which is best for a fid. From the below analysis, it appears the answer is sort of yes and no, as we shall see. This article, I hope is not too difficult to follow in detail, and if it is, I apologise for its non-clarity. I also apologise for the prolix writing on such a simple device. Some basic principles of mechanics and a bit of geometry is all that is needed here. I would hope some possible knowledge gained here could be used to advantage in understanding other AYRS articles.



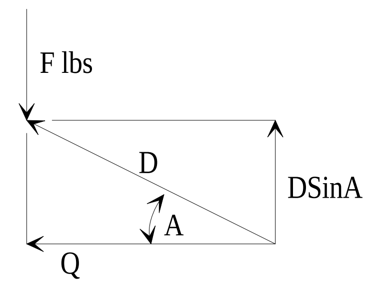


Radius of Contact Circle $r = R - RCosA = R(1-CosA)$
Circumference of Contact Circle $= 2\pi R(1-CosA)$

For purpose of analysis, we must visualise an ideal knot. This is shown in the first sketch included here. It is a doughnut shaped figure with an infinitely small hole in the middle. Into this doughnut, we force the fid. The question is: What force on the knot is produced for each pound of force we push on the fid. Intuitively, you know that the smaller the semi-angle of the point of the fid, the easier it is to force through the knot, but at the expense of having to push further and requiring a longer fid. So we have three variables here: the force ratio, the semi-angle of the fid, and the half diameter the knot is forced open for each inch of drop of the fid. We look for an optimum combination of these variables.

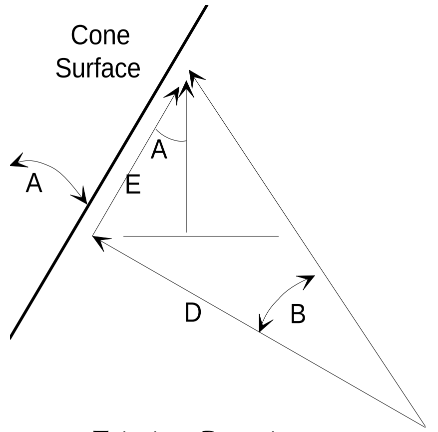
We must first examine the geometry of the fid point where it contacts the ideal knot. You can see there is a circle of contact that the fid makes with the knot. For the moment, we will assume there is no rope compression and that the circle of contact is indeed a circular line whose circumference is easily determined from the radius of the rope, R. We call this smaller radius r and the contact length is as shown on the sketch. Thus our downward force is distributed around a very small circle as we push down on the knot and this circular distribution is what opens the knot. We must also realise that we are generating a pounds per inch of circumference of the small fid circle and thus to get a force, we must multiply the pounds per inch of circumference by a length – the circumference.

Now let us look at the two force diagrams, one due to our downward force F and one due to rope friction. The downward force generates a reaction force D, a "normal" force perpendicular to the surface of the fid. If we wish, from the laws of



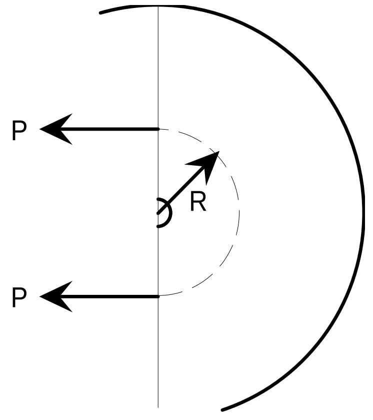
Rope Reaction

Vertical Reaction to Push Force
= DSinA.2πR(1-CosA)



Friction Reaction

TanB = E/D, E = DTanB
So Vertical Friction Force = ECosA
= DTanB.2πR(1-CosA)CosA



Plan View of Idealised Knot

From the Hoop Tension formula
P = Q.R

mechanics, we can resolve this force D into a vertical force D.SinA, and a horizontal force Q. Q is a factor opening the knot. The friction force is E and acts parallel to the cone surface and of course resists our push on the fid so it is in an up direction. Physics tell us a friction force is a function of the normal force, D, and the coefficient of friction angle B. The larger B is, the larger the friction force generated. This friction force relation is shown in the friction diagram and we see it is a function of the tangent of the angle B. The friction force generated can be zero, 1, or any number in between, and on up to infinity, meaning you could never open the knot due to infinite friction. The friction force is distributed over the same circle as D is. Strictly speaking, friction is generated over an area so we must assume that there is some rope compression but let us say not enough to disturb the geometry too much.

Physics further tells us that in a static condition, the down forces must equal the up forces, that is the vertical forces. Further, keep in mind the forces D and E are forces per unit length and they must be multiplied by a length before we can plug them into a force formula. This length is of course the small fid circle circumference whose radius is r. Therefore the vertical downward force F must equal the vertical component of D times a length plus the vertical component of the friction times a length. The algebra for this is shown in detail and we can then solve for D. Knowing D, we can find the horizontal force per unit length, Q, which is what we have been looking for, the force per unit length to open the knot.

If we now examine the plan view of one half the idealised knot we bring in the force P, which is the force causing tension in the rope knot. From the Hoop Tension Formula (from a handbook) due to The Calculus, it can be shown that P equals Q time R, the idealised knot radius. And thus knowing P and F, we can find their ratio P/F which it turns out is a function of the fid semi-angle and the friction angle B.

Now refer to the plot of fid semi-angle versus Ratio of P/F. Three curves are plotted for fid semi-angles up to about 15 degrees which would make a fid with an angle of 30 degrees: 0 friction coefficient, 0.4 coefficient, and 1.0 coefficient.

Solving for D

Force Down = Force Up

So: F = DSinA.2πR(1-CosA) + DTanB.2πR(1-CosA)CosA

$$\text{Hence } D = \frac{F}{2\pi R(1-\mathrm{Cos}A)(\mathrm{Sin}A+\mathrm{Tan}B.\mathrm{Cos}A)}$$

Now the Horizontal Force to open the Knot, Q, equals DCosA

$$\text{So: } Q = \frac{F}{2\pi R(1-\mathrm{Cos}A)(\mathrm{Tan}A+\mathrm{Tan}B)}$$

From the Hoop Tension formula, P = Q.R, so by cancelling R, we get:

$$P = \frac{F}{2\pi(1-\mathrm{Cos}A)(\mathrm{Tan}A+\mathrm{Tan}B)}$$

Finally, the ratio of P:F is

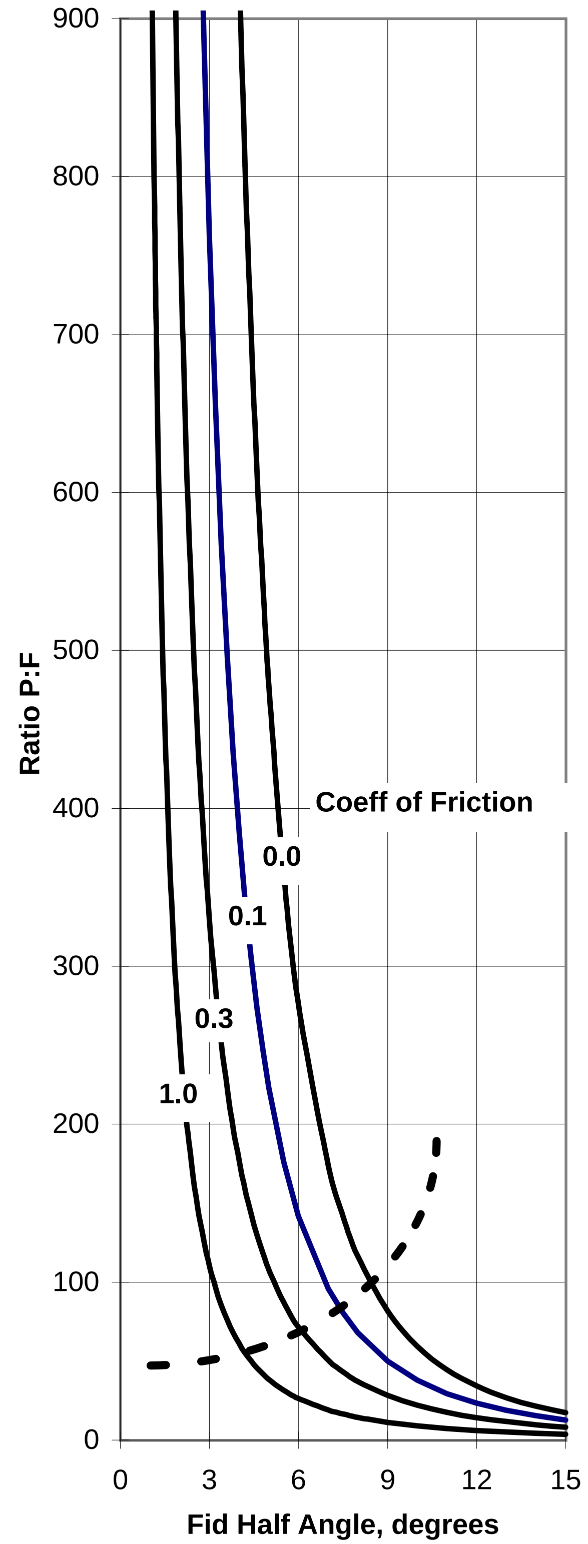
$$P/F = \frac{1}{2\pi(1-\mathrm{Cos}A)(\mathrm{Tan}A+\mathrm{Tan}B)}$$

From the plot you can see a large force ratio is generated for smaller angles and less friction. Also shown against the angles is the half knot opening per inch of drop of the fid.

We now have 3 variables to consider to arrive at the best fid: fid semi-angle, 1/2 drop, and the force ratio. By inspection and choosing a coefficient of friction and a force ratio, we could arrive at a conveniently shaped fid. Thus our task might be done. However, there is one other thing we can do to narrow down our choice of fid angle. It almost appears the hand of God has given us help in determining the proper fid angle.

We can see from the plot that the three curves approach zero angle at infinite P/F ratio on the vertical axis and the curves approach zero P/F ratio on the horizontal axis when the angle is infinite. Thus the curves at each end are continually getting closer to each other. Therefore you must assume that there is an area on the plot where the lines are furthest apart from each other. This no doubt can be figured out mathematically (Is the line straight, curved, perpendicular to the curves, does it go through 0?) but for our purpose, a set of dividers and a visual examination of the plot will do. The dotted line on the plot is approximately the longest line we can draw between the curve for no friction and the one where the friction coefficient is 1. This, I submit, is the area of choice for our fid total angle. It appears to be the point on each curve just before the force ratio takes a nose-dive.

A few final words. It's a good idea to wax or lubricate your fid. From the curves, you can see why a marlinespike used on wire cable has a much smaller cone angle than a mere fid on rope, but at the expense of a longer push. From the algebra, you can also see that the angle of the fid is independent of the rope diameter so one fid fits all rope sizes, perhaps it is self evident, but interesting geometrically. You should also be careful that the P pounds force you generate does not cause too much stress, that is pounds per square inch of cross sectional area of your rope so that it approaches breaking force. We could also examine the fid from the viewpoint of hammering the fid into the knot and consider impact and rope stretch and elasticity and rope breaking strength but we will save that for some other time. Would it be meet to have a boxed set of fids with assorted angles? Let us hope all you good sailors out there will keep your lines from fouling so that you will not have to use a fid. However, the next time, you use a fid, check its angle and see how it fits with the curves shown.



Plot of Mechanical Advantage produced by Fids of different half-angle, under varying friction coefficients

Catalyst Calendar

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

January 2001

4th-14th London International Boat Show
Earls Court Exhibition Centre, http://www.bigblue.org.uk *(AYRS will be there as usual)*

13th AYRS Annual General Meeting
19.30 for 20.00hrs at the London Corinthian Sailing Club, Upper Mall, London W6. Matters for the Agenda should be sent to the AYRS Secretary, BCM AYRS, London WC1N 3XX, UK; tel/fax: +44 (1727) 862 268; email: ayrs@fishwick.demon.co.uk to arrive before 1st December 2000

26th-27th 15th Chesapeake Sailing Yacht Symposium
Annapolis, Maryland, USA. Sponsored by the Society of Naval Architects and Marine Engineers, US Sailing, the Chesapeake Bay Yacht Racing Association & the Naval Academy Sailing Squadron. Details at http://wseweb.ew.usna.edu/nahl/csys/ email: anderson@gwmail.usna.edu

February

6th AYRS London meeting
Subject to be announced. 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

March

6th AYRS London meeting
Subject to be announced. 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

3rd AYRS London meeting
Subject to be announced. 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

September

29th-5th Oct Weymouth Speed Week
Weymouth Sailing Centre, Portland Sailing Academy, (old RNAS helicopter base) Portland Harbour, Dorset UK. Contact: Bob Downhill, 40 Collingwood Close, Eastbourne, UK; tel: +44 (1323) 644 879 email: robert@speedweek.demon.co.uk; http://www.speedsailing.com

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

On the Horizon . . .

Low Reynolds Number Aerodynamics — Tom Speer
The Maximum Speed of Yachts — Bob Dill
Electric Propulsion Design — Theo Schmidt
Alerion Electric Auxiliary Conversion — Charles Houghton
Wind Direction and Sails —Mike Brettle
Inspired Designers — Jim Champ
Taking a Seadog for a Walk - Robert Biegler
More sources and resources: reviews, publications and Internet sites

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