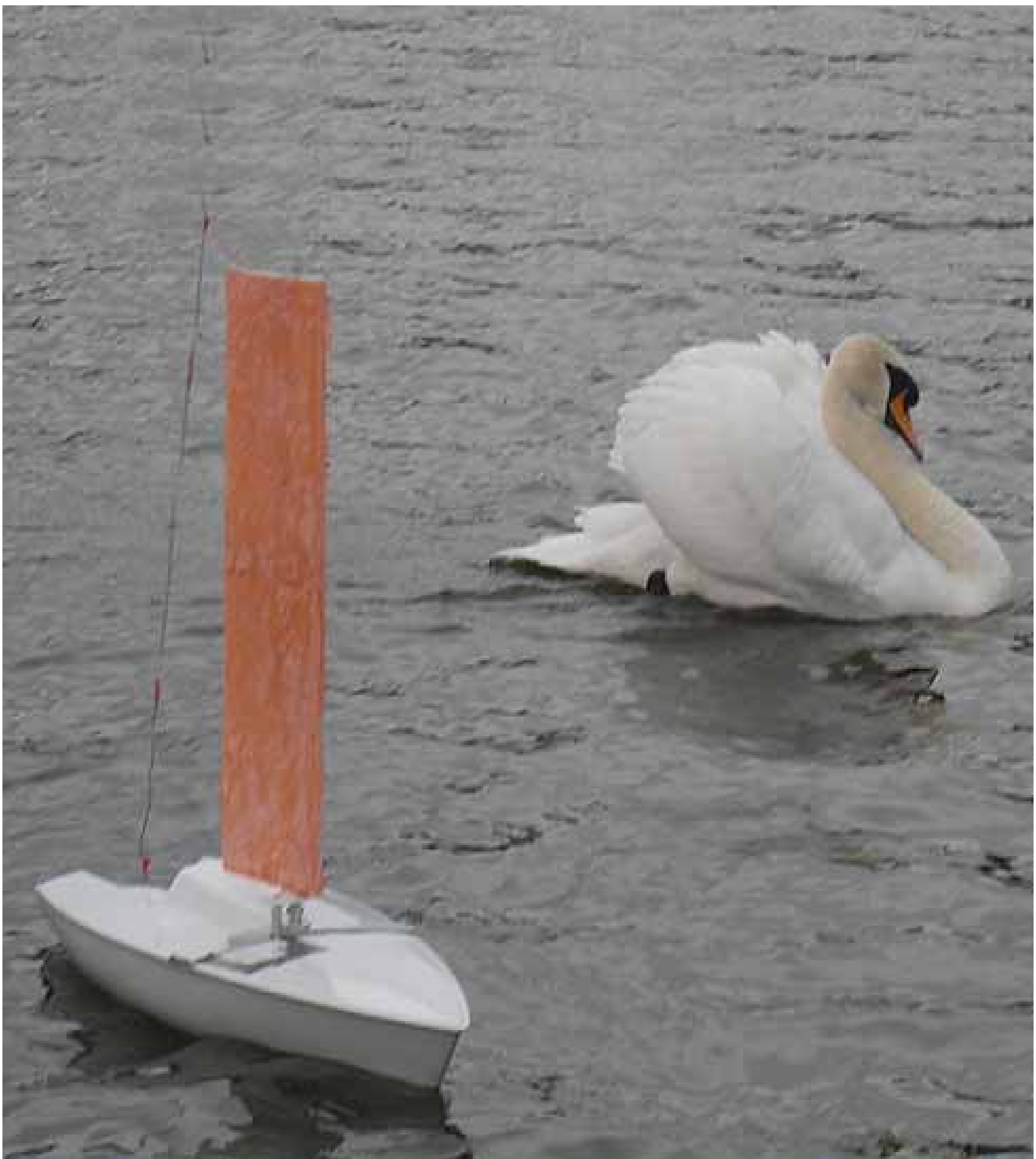
Catalyst

Journal of the Amateur Yacht Research Society

NUMBER 39 JULY 2010



WoodenBoat and *Professional BoatBuilder* magazines'

DESIGN CHALLENGE III

A Fast Expedition Sailboat

Inspired in part by the worldwide popularity of raid-type events—multi-day racing and cruising expeditions sailed in small boats—we challenge you to design a new boat within the following parameters:

- Must be a new design produced after September 1, 2010.
- Fast, seaworthy, and simple.
- Must have spartan overnight accommodations for a minimum of two. These accommodations must include a cabin, cuddy, or boom tent; a port-a-potti; and a limited galley that includes a stove and water and food storage.
- Must be trailerable for affordable over-the-road transportation and storage. Maximum LOA must not exceed 40'; maximum over-the-road beam (with trailer) must not exceed 8'6"— although the rigged sailing beam may be greater. We'll look favorably upon designs that are easily launched, rigged and retrieved without outside assistance. Water ballast and adjustable keels are permitted.

Above—Swallow Boat's Bay Raider 20, a water-ballasted yawl. For more information, see www.swallowboats.co.uk/content/view/115/110

Top—The 24' Kurt Hughes–designed trailerable trimaran MUFFOLO built by Luciano Romano and operated by Silentbay Charters in Sestri Levante, Italy. Photo: Andrea Sesta

- Maximum trailerable weight must not exceed 3,500 lbs.
- The boat must have positive flotation, watertight storage for gear, and mechanical or manual auxiliary propulsion.
- And, finally, the boat must have good seakeeping attributes with the ability to sail to windward in a gale (34–47 knots).

Submissions must be the designer's original, previously unpublished work, and include lines, profiles, sections, table of offsets, an accurate weight study, and cost calculations. All designs will remain the property of the designers, although WoodenBoat Publications requests the right to publish drawings of the winning boats.

Submissions should be postmarked no later than April 29, 2011. Please send hardcopy only. Include your e-mail address if you would like to receive notification of receipt.

We will award $1,000 prizes to each of our first-place designs in wood, composites, and metal.

DESIGN CHALLENGE III
***WoodenBoat* magazine**
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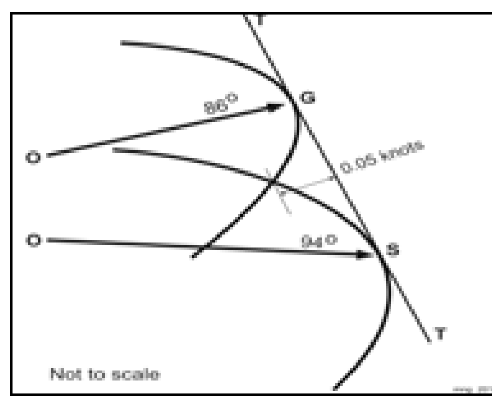
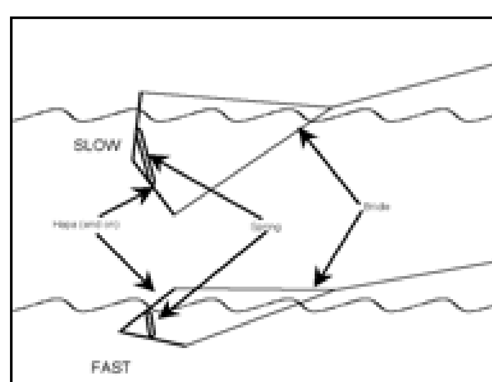
For more details email carl@proboat.com
or visit our Web sites at **proboat.com**

Features





Regulars

A swan admires the UCD Roboboat photo: Brendan O'Driscoll

Catalyst

Journal of the
Amateur Yacht Research Society

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

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Catching Up!

Although this issue (No 39) carries the cover date of July 2010, it wasn't actually produced until November. So it's five months late. However that's an improvement over the last one, which was seven months late. So I'm getting better. I hope to get another (No 40) to the printer before January. Whether it gets to you in that timescale remains to be seen given that Christmas is in the way.

But the long lapse with no Catalysts has meant that people have stopped sending me articles. I certainly don't have enough to fill No 41, and I'm not sure about No 40. So why don't you fill the long, dark, evenings (or, if you're in the Southern Hemisphere, the long, light, evenings) writing something for Catalyst which you can email to me at editor@ayrs.org or send by post to the address opposite (please enclose a disk with the text on – I'm terrible at reading handwriting!). Then I can do No 41 and maybe No 42 as well before April.

PS See the inside back cover for details for the AGM in January.

Best wishes
Simon Fishwick

Subscriptions

To those who have already paid their 2010-11 subscriptions, be that by bank transfer, cheque or PayPal, thank you very much. Your unprompted support is greatly appreciated.

To those who have not, you should note that the subscription year ends with this issue of *Catalyst*, and that subs are due. For rates and methods of payment please see the website www.ayrs.org/joinayrs.htm. If you have doubts about you subscription position, please email us for clarification at office@ayrs.org

Thank you

Meet the Committee – Part 2

In the last Part, we introduced you to the Chairman (Graeme Ward) and Vice-Chairman & Secretary (Sheila Fishwick). This time it is the turn of:

Slade Penoyre – Treasurer

Slade joined the Committee in the 1990s and became Treasurer in 1998 – a post he has held ever since. In theory, the Treasurer is responsible for all things financial; in practice, the day-to-day managing of money within AYRS is so bound up with the management of memberships and of publication sales that most of it is done by Simon & Sheila, and Slade simply exercises an overview.

Slade is a retired civil servant, with an interest in aviation as well as sailing. He was part-owner of *Lillian*, a Kelsall-designed, Tony Smith-built, Atlantic proa which unfortunately capsized in the Celtic Sea after qualifying for the 1976 Single-Handed TransAtlanrtic Race; an incident which has left him ever since with strong views on the seaworthiness of proas offshore. His current pre-occupation is with the generation of electricity by small, mass-produced, floating wind-power generators to be deployed in quantities large enough to bring down the unit cost of construction and operation to rates competitive with onshore power sources.

Simon Fishwick – Editor

A member of AYRS since 1967, Simon joined the Committee at the end of the 1980s, edited the Newsletter in the early 1990s (under Tony Kitson & Ian Hannay) and became Editor in succession to Ian in 1999. A Chartered Engineer working on air traffic control systems, he has worked with small computers all his professional life and had a working word-processor in his office long before IBM and Microsoft introduced the PC (his employers thought it was a research tool!) . He was therefore the "obvious suspect" to help AYRS move from typewriters and offset printing to desk-top publishing. Pushed by Dave Culp and Tom Blevins (then organiser of the New England AYRS Group) his tenure has seen the birth of *Catalyst,* and he has edited most of them after Tom, who edited Nos 1 & 2, had to give up under the pressure of work. His (Excel) skills also allowed AYRS to move its financial records to computer (the membership records being already computerised by Michael Ellison).

Having retired from engineering, he & Sheila now run an adventure centre and sailing school on the Norfolk Broads, a job that was meant to be part-time, but now seems to occupy 100% of their days (and many nights) from April to October! They would like to give up the task of editing *Catalyst*, preferably to someone better skilled than they. (There are lots of such people are out there, we merely have to find them!)

In brief, that ideal someone would need at least:

a) The technical knowledge to review potential articles, and the technical confidence to recognise errors, propose changes, and, if needs be, reject the rubbish. (By implication - they are likely to have been a member of AYRS for a few years);
b) The design skills to plan and deliver a product attractive both to subscribers and the public at large;
c) The computer skills, and facilities*, to produce that product (*Catalyst*) ready for printing;
d) The spare time to get it done four times a year!

NB Printing & distribution would remain in the hands of the Secretary/Treasurer, whoever holds the membership records.

Potential Editors please apply quickly!

Having disposed of the Officers of AYRS in Parts 1 & 2, the next Parts will introduce the remaining Committee Members.

* InDesign or Quark, plus Acrobat to produce a text, not image, PDF file.

The UCD Roboboat

Brendan O'Driscoll
University College Dublin, Ireland

Swan Admiring the UCD Robo-boat

Introduction

This project investigates wing sail propulsion, especially for use in an autonomous sailing context, and examines the advantages associated –simplicity of design, robustness and ease of use.

By definition, a wing sail is described as an airfoil which produces lift to drive a boat. The theory of wing sails is similar to the theory of a wing from a plane. Just as the difference of speed of flow of air over the top and bottom of an airplane wing causes a change in pressure with a corresponding increase in lift, so too does a wing sail generate lift from the airfoil shape of the sail.

This project, on behalf of University College Dublin (UCD) is working to enter a fully autonomous boat in the "Micro Transat Challenge". The "Robbe Estelle" 1.1 m model boat is being used to test new ideas and configurations before being scaled up to the larger 3.5m "Laerling" competition boat. The overall goal is to test to see whether a future entry should be equipped with a wing sail propulsion system.

Figure 1: UCD Laerling 3.5m boat

Why?

There are many reasons to research autonomous sailing. According to the International Robotic Sailing Conference held in Austria in May 2008, the ultimate goal of researching this area is to develop a robotic sailboat that is able to autonomously navigate towards any given target without human control or intervention. Roland Stelzer, the conference chair, states that the robotic boat should have the ability to *"operate in a highly dynamic environment … and respond quickly to changing environmental conditions. Incoming data from sensors (GPS, compass, anemometer, etc.) have to be analysed permanently by intelligent control mechanisms".*

There are several reasons why such a boat could be beneficial, especially to the scientific community. In his paper *"A reconfigurable computing system for an autonomous sailboat"* Jose Alves highlights several potential uses of such a boat:

- Data acquisition of oceanographic or atmospheric variables
- Wild life tracking and monitoring
- Surveillance
- Support platforms for cooperative navigation with autonomous underwater vehicles

In their paper *"Design Considerations for Sailing Robots Performing Long Term Autonomous Oceanography"* Colin Sauze and Mark Neal observe that autonomous sailing boats can be cheaper, more flexibly deployed and possibly replace:

- Data buoys
- Survey ships
- Satellites

The Micro-Transat

The Micro-Transat challenge is a trans-Atlantic race for autonomous sailing boats which aims to "stimulate the development of autonomous sailing boats through friendly competition".

- Every boat entered must fulfil the following criteria:
- No source of propulsion other than wind.
- The sailboat must be fully autonomous, no operator control is allowed.
- The sailboat must be energetically autonomous, carrying on board any required batteries and electricity generating equipment.
- The length of the boat must not exceed four metres.

Autonomous Sailing

In manned sailing, conventional sails offer several advantages over alternative sails. Firstly they may be reefed in high winds to reduce the sail area and hence reduce the forces on the sail. The sails may be altered and the camber may be changed during operation by adjusting a series of ropes. It is possible to take down a sail and erect a sail of a different size when weather conditions change.

However, conventional sails also have several disadvantages. They have the ability to collapse if not enough air is kept in the sails (luffing). They also twist which produces different angles of attack at various points along the sail leading to inefficiencies.

In autonomous sailing, the many variables of conventional sail propulsion are hard to automate – this validates an investigation into an alternative propulsion system.

Having witnessed other teams experimenting with wing sail propulsion, this project came to life. This investigation into wing sail propulsion will include designing, developing and testing a prototype model which can in be analysed to see whether wing sails represent a feasible method of propulsion for the UCD entry into this competition.

Autonomous Sailing Research at UCD

UCD has made a significant contribution to autonomous sailing research through the "Laerling" and "Robbe Estelle" boats. To encourage further developments in this field UCD plan to prepare an entry to compete at the "MicroTransat" challenge competition for autonomous sailing.

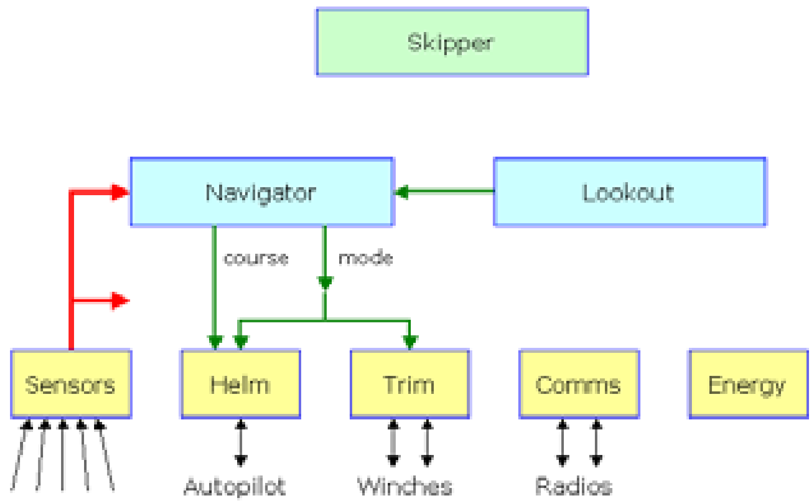


Figure 2: Laerling Control System

Laerling

The "Laerling" boat is UCD's first prototype autonomous sailing boat. Measuring 3.75 m in length, the boat's hull is moulded in one piece, including the keel. The mast height is 4.33 m and is supported by a forestay and two shrouds.

The boat is equipped with conventional sails, with the mainsail having an area of $3m^2$, the jib $1.5m^2$ and the spinnaker $5m^2$.

Figure 2 illustrates the control system set in place for the "Laerling" boat. The Sensors block is responsible for gathering all the required data. Battery voltage, autopilot current, boom angle, rudder angle, boat speed, wind speed and wind direction will all be sensed and recorded. The Helm block ensures that the boat steers the prescribed course. The Trim block controls the actuators and ensures that the sails are set in their required positions according to the wind conditions. The Communications block (Comms.) handles the radio communications with other boats and the Energy block monitors energy collection and use.

The Lookout block represents the controls that will detect other boats, identify collision risks and recommend avoiding action.

Robbe Estelle

The "Robbe Estelle" is the 1.1 m scale model boat this project is based on. This model boat has been modified by UCD for autonomous sailing and serves as a platform for investigating and testing ideas before developing for the larger UCD "Laerling" boat.

The boat uses conventional sails for propulsion and is equipped with several sensors to help with testing. The sensors include a digital compass, wind vane, anemometer, tilt sensors and paddle wheel for boat speed.

Servo motors control the main sheet and the rudder.

It is a replica of this model boat that will be modified with a wing sail instead of conventional sails as a method of propulsion and tested throughout the duration of this project.

Figure 3: Robbe Estelle Model & Servos

Wing Sail Advantages in Autonomous Sailing

When considering wing sails for use in autonomous sailing, it is clear that they offer several advantages over conventional sails.

One of the main advantages of wing sails is that they can be mechanically rotated to produce drive in the forward direction, irrespective of wind direction. This allows a simple control system consisting of a wind vane, potentiometer and DC motor to set the optimum angle of attack with ease.

A rigid wing sail configuration is far more efficient than a cloth sail. The lift to drag (L/D) ratio is much higher than a conventional sail and due to the fact that there are no aeroelastic problems that a conventional sail faces (collapsing sails due to variations in the wind) the drag is reduced, maximising efficiency.

Airfoils

The shape of the wing sail is an airfoil shape. The most common airfoil shapes can be found in standardised airfoil databases. One of the most widely known and used airfoil databases was developed by the "National Advisory Committee for Aeronautics" which was set up in 1915 to promote aerodynamic research. It has since been disbanded and reformed as the National Aeronautics and Space Administration (NASA).

The advent of modern simulation and design software has allowed for airfoils to be tailored to very specific needs as opposed to selecting an airfoil from a pre-existing database. However, for the purpose of this project a standard NACA airfoil was selected. This allowed for the use of published theoretical data for the standardized airfoil as well as simplifying computer simulations involving the airfoil.

Airfoil Classification

There are several different classes or families of NACA airfoils with the 4 digit classification being the most common. The system of classifying NACA airfoils is based on their geometry. The method of describing a NACA 4 digit airfoil is presented below.

The 1st digit describes the maximum camber as a percentage of the chord. The camber relates the asymmetry between the top and bottom curves of an airfoil in cross section. The chord is a straight line joining the trailing edge and centre of curvature of the leading edge.

The 2nd digit relates the distance of maximum camber from the leading edge in tens of percents of the chord.

The 3rd and 4th digits describe the maximum thickness of the airfoil as a percent of the chord.

Airfoil Symmetry

If the first two digits of the NACA 4 digit code are zero, there is no camber on the airfoil and the airfoil is perfectly symmetrical. A symmetrical airfoil has the advantage of having identical lift and drag characteristics for both positive and negative angles of attack.

Asymmetrical sails have several disadvantages. Due to the fact that the characteristics vary for positive and negative angle of attack, the sail must adopt an over-the-top tack. This type of tack incorporates lifting a sail about a pin located halfway up its span, holding at its horizontal position, and then flipping the sail completely until it rests on the other side of the boat as illustrated below. This setup is considerably more complicated and leads to issues when considering automated sailing.

NACA 0012 Airfoil

The NACA 0012 airfoil is a symmetrical foil with its maximum thickness being 12% of the length of the chord.

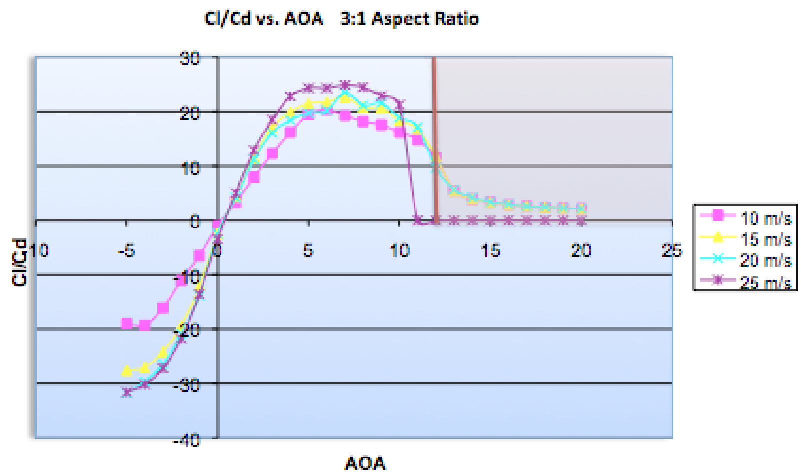
The main reason that the NACA 0012 was chosen for this project was due to its selection in a previous "Roboboat" project in which a computational fluid dynamics investigation was partly carried out on a NACA 0012 wing sail. This meant that simulated data collected previously could be related to the work carried out in this project.

NACA 0012 Wind Tunnel Testing

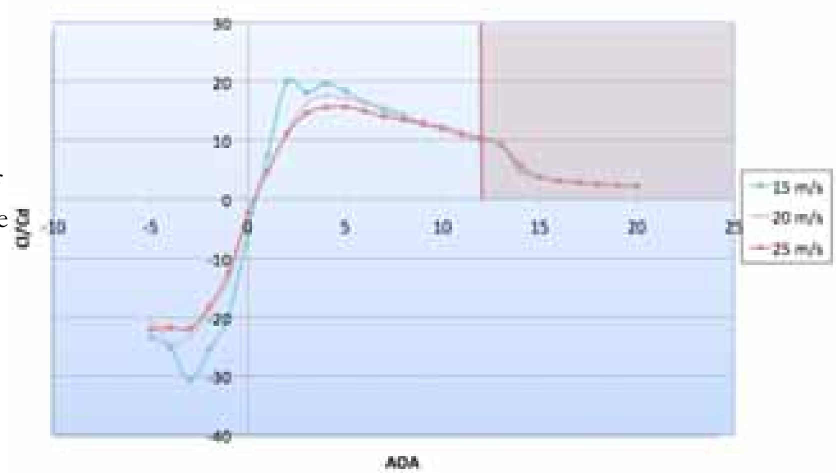
The first step taken in this project consisted of an experiment using the UCD wind tunnel. To gain an appreciation of the characteristics of the NACA 0012 airfoil and to determine experimentally the optimum angle of attack, several airfoil spans were tested using the wind tunnel located at UCD. Not only did this experiment help to define the optimum AOA but it proved the theory established in the first chapter that wing sails could achieve superior lift to drag characteristics over conventional sails, the theory on which this project is based. Also, using three NACA 0012 airfoils of different spans (different aspect ratios) allowed for potential wing sail designs to be tested experimentally to help with future design considerations.

After all the data was gathered from the experiment and the calculations performed, the points were organized and plots of the lift and drag coefficients against the angle of attack of the airfoil was created. These graphs, shown right, allowed for the optimum angle of attack to be determined. This was calculated by examining the lift curves and determining the maximum angle of attack before the stall occurs.

Stall, is the term given to the point where lift dramatically decreases as airflow over the wing is not creating a pressure difference needed to produce lift. A clear drop in the curve illustrates this effect. Stall occurs due to the separation of flow of air from the airfoil. After the critical angle of attack is surpassed the smooth laminar flow over the airfoil begins to detach from the surface and is replaced by turbulent flow. When this occurs the wing dramatically loses its lift and drag is quickly increased.



Cl/Cd vs AOA for NACA 0012 Airfoil – Aspect Ratio 3:1



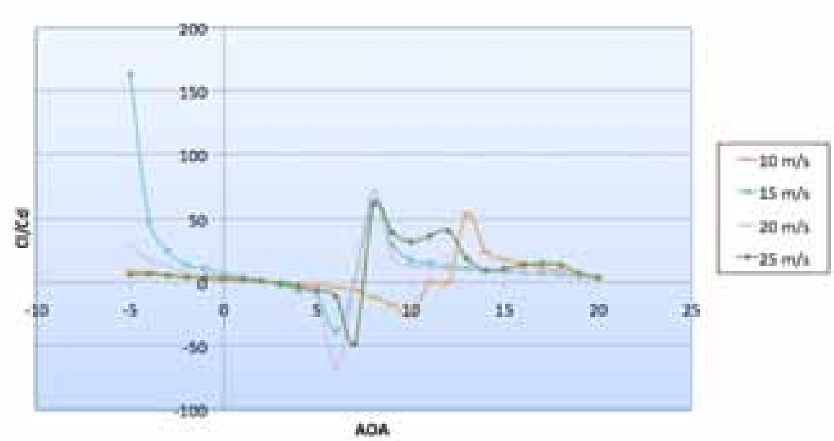
Cl/Cd vs AOA for NACA 0012 Airfoil – Aspect Ratio 2:1

Simulated Results

A NACA 0012 airfoil was generated in the DesignFoil* computer package and a simulation was run using the virtual wind tunnel feature of the programme. The angle of attack was set at 12degrees (the optimum angle of attack found in the experiment) and the wind speed was set at an average of 5m/s.

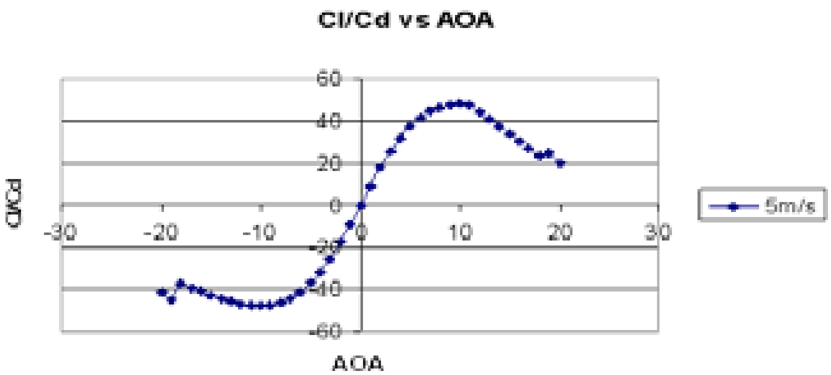
The plot of Coefficient of Lift vs AOA and Coefficient of Drag vs AOA for an average wind speed is shown opposite.

The theoretical graphs established from the virtual wind tunnel with a



Cl/Cd vs AOA for NACA 0012 Airfoil – Aspect Ratio 1:1

* DesignFoil - see http://www.dreesecode.com/



Simulated Cl/Cd curve for a NACA 0012 Airfoil

NACA 0012 airfoil show that the optimum angle of attack is 12degrees as established in the experiment. The theoretical graph displays a higher Cl/Cd. This can be explained by the inaccurate readings of the apparatus and by the increased drag due to the worn airfoil samples.

Generation of Design Concepts

Three design concepts for the wing sail prototype boat were developed and reviewed before the fabrication stage. The designs were modelled using a software package (Pro/Engineer+) which allowed for the concepts to be reviewed after each stage in the progression of the concepts. Two further computer software programmes were used. "Profili 1.2" was used to draw the airfoil. The virtual wind tunnel simulator in "DesignFOIL" allowed for theoretical data to be compared with experimental data collected from testing in the UCD wind tunnel.

Design Concept #1

In this initial design, a dual hull (catamaran) was developed. The principle reason for the selection of a catamaran hull was due to the extra stability a multi-hull boat provides. Looking back through the history of wing sail boats, it is evident that multi-hull boats were favoured (PlaneSail (1968), Flyer (1972), Blue Nova (1990), Zepher (1996), Atlantis (1997), BMW Oracle (2009)).

+ See http://www.ptc.com/products/creo-elements-pro/

Multi-hull boats have an advantage over mono-hulls in that they are more stable. Their wide stance in the water ensures that the boat does not heel very much. Figure 4 illustrates the heeling angles for a typical mono-hull and multi-hull boat. It is clear that the mono-hull experiences higher angle of heel which in turn lead to increase capsizing potential. The multi-hull boat has the ability to remain at lower more constant angles of heel even in high winds.

The stability of multi-hull can be seen when calculating a simple moment balance. The moment arm to the buoyancy force is much larger than a single hull boat.

The principal reason that this initial design concept was revised was due to the fact that the other model boat is a mono-hull. Designing a multi-hull wing sail would not allow for a comparable study to test performance to be carried out between the two model boats.

Also, since the model boat serves as a testing platform for the larger "Laerling" 3.5m mono-hull boat, any tests carried out on the model boat could not be scaled to reflect how the larger boat would perform. A complete overhaul of the entire Robo-boat project would have to occur to facilitate this design. Therefore a second design concept was developed which incorporated a single hull into its design.

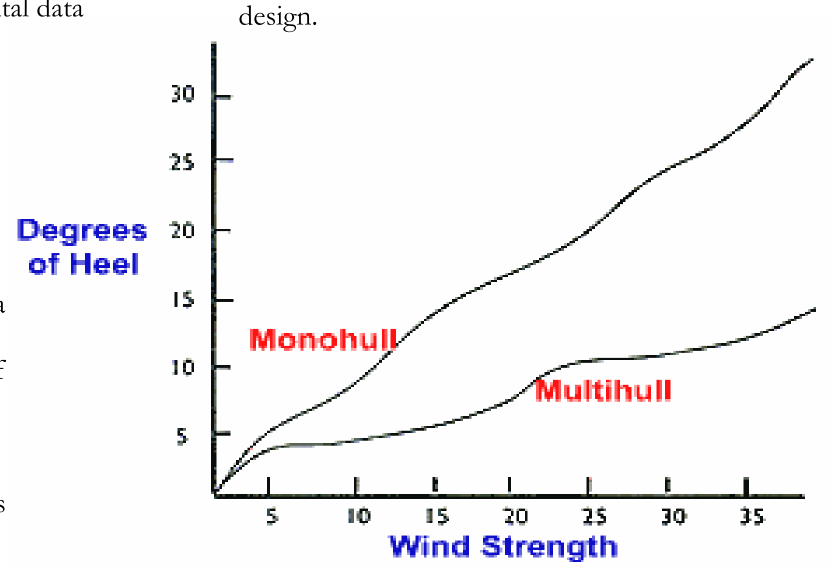


Figure 4: Graph plotting degrees of heel against wind strength for a mono and multi hull boat

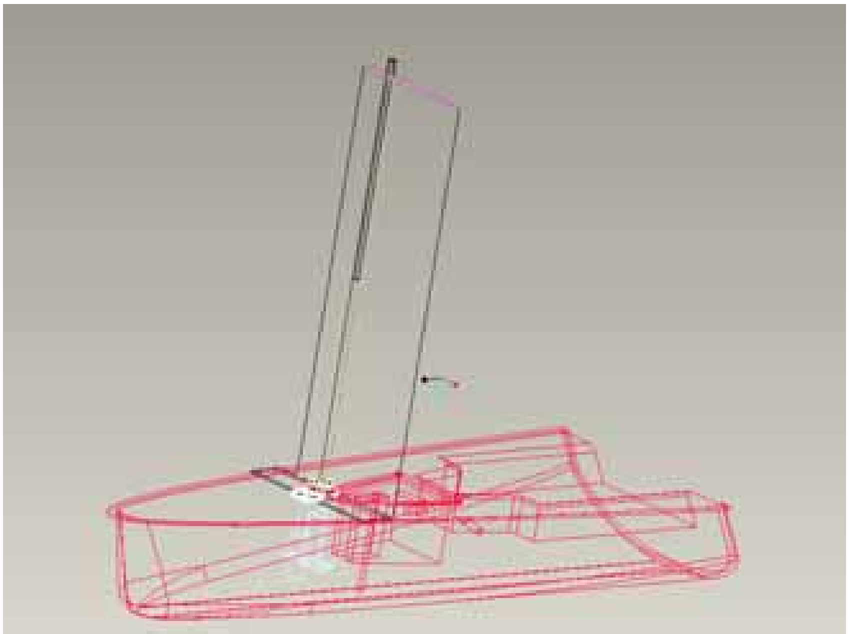


Figure 5: Wire drawing of design concept 3

Design Concept #3

This concept, which does not include stays, does have an extra support designed for the base of the mast.

Also, the gears are now housed above deck, to aid in the assembly and alignment. A nylon bearing attaches to one of the gears and it this gear that is rotated by the driving gear to turn the sail. Initially, the gears were to be housed underneath the deck and the mast was to protrude through the deck, supported by a bearing at the base. .However, concerns raised about friction between the mast and the support, lead to a redesign. The stationary mast, now entirely above deck, holds the wing which is rotated using a nylon bearings and gears.

Design Concept #2

The second design concept incorporated stays in its design. The purpose of a stay on a conventional boat is to limit the bending of the mast. The mast on a conventional boat deflects under the force of the wind in a downwind sail. In downwind sailing, a regular boat uses its sails to act as a resistance to the flow of air and hence the drag force created "pushes" the boat through the water. The high forces imparted on the sail by the wind cause the mast to deflect. The high strength wire rigging connects the top of the mast to the deck of the boat. Without stays (or in very high winds), masts have the ability to buckle under these high forces.

However, for wing sails, since they do not utilise drag forces as a method of propulsion, the mast does not experience these high levels of deflection. The air flows smoothly over the aerodynamic shape of the airfoil and lift is generated and utilised as a means of propulsion. There is no need therefore for stays for a wing sail.

Therefore, upon closer scrutiny of this concept, it was decided to remove the stays and shorten the mast for the third concept.

Design of Wing

Designing the correct wing sail was a crucial part of this project. The sail needed to be large enough to produce enough lift (and hence driving force) without being too large that the heeling forces generated or the added weight above the centre of gravity could capsize the boat.

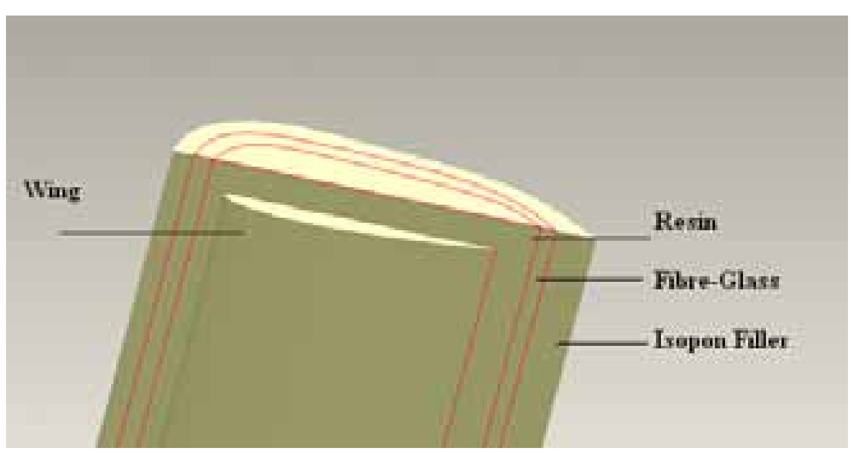


Figure 6: Layers of Wing

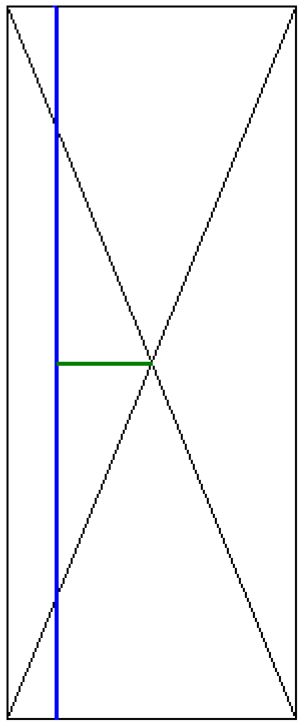


Figure 7: Simplified representation of wing to calculate lever arm

Wing Dimensions

Once the NACA 0012 airfoil had been selected, the next step was to specify the chord length and height of the sail. To begin, an approximate set of dimensions was used as a starting point. To obtain an idea of the scale of the wing to the size of the model boat, the dimensions of the MOOP 0.7m model boat (University of Aberystwyth Micro-Transat entry) were used as a reference.

The dimensions of the MOOP were noted and proportionally scaled to the size of the 1.1 hull of the Robbe Estelle model boat. Next, the aspect ratio of the MOOP wing was altered from 4:1 to 3:1. This was done for two principle reasons. Firstly, it was noted that the MOOP was prone to capsizing. By reducing the aspect ratio to 3:1 the probability of capsizing was reduced. Secondly, the lift and drag data collected in the laboratory experiment was for a NACA 0012 airfoil with 3:1 aspect ratio. By choosing a 3:1 aspect ratio for the prototype, the forces could be scaled and compared for a clear idea of the forces the prototype could generate.

The table below shows the dimensions, aspect ratios and areas of the three different sail sizes.

Stability

To ensure the dimensions of the wing would not adversely affect the stability of the boat, some simple calculations were carried out. For experimental data gathered in the UCD wind tunnel, the highest heeling force at the highest encountered wind speed (maximum wind speed of the tunnel (approx. 30m/s)) was recorded to be 25N. This force, at a predetermined maximum heeling angle of 20degrees was then used to calculate the righting moment. The righting moment was compared against the counteracting moment produced by the keel.

From these calculations, it was noted that the keel moment could counteract the highest heeling moment if a ballast weight of 2kg were added (weight of motor, electronics etc.).

$$F = M \times a$$

where: F = Force, M= Mass, & a = acceleration

$$\tau = F \times d$$

where: F = Force, d = Distance, & τ= Torque

The righting moment of the boat was simply found by calculating the force exerted by the weight of the boat and multiplying by the distance from which it acts (the lever arm).

Figure 7 shows how the lever arm (thick line) of the boat was calculated. The distance between the centroid (intersection of the two diagonals) of the sail (assumed to be a rectangle) and the mast (located at 26.5% of the chord at the centre of pressure) was recorded to be 0.14m

Model	Hull Length (cm)	Wing Dimensions (cm)	Area (cm^2)	Aspect Ratio
MOOP	72	52.5 x 13	682.5	4:1
Rob Estelle	110	64.5 x 16	1032	4:1
Rob Estelle	110	56.5 x 18.5	1045	3:1

Table of Wing Sail Dimensions

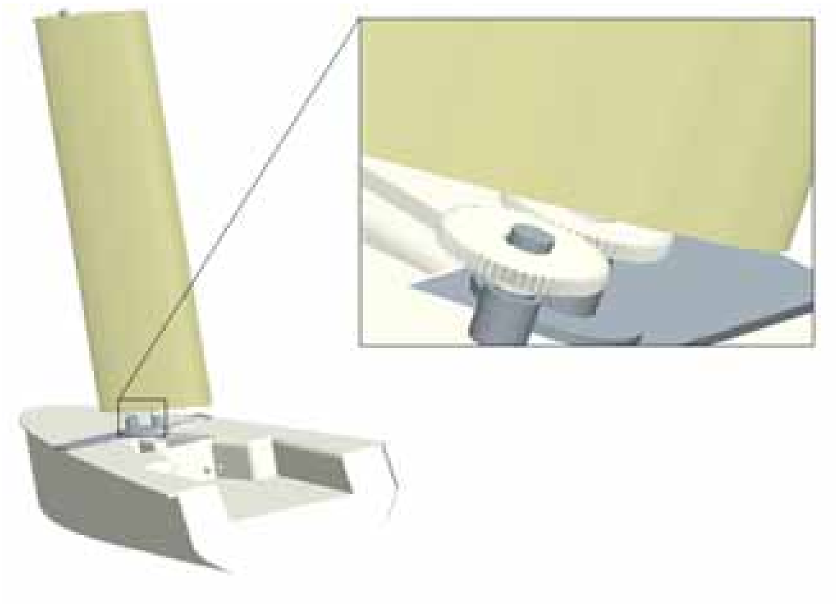


Figure 8: Screenshot of NACA 0012 airfoil in "Profili v1.2"

The force was calculated by multiplying the weight of the boat 4.2 kg by gravity (9.81m/s2). The weight of the boat was an approximate measure, taking the initial 2.2kg weight and estimating for the added weight of the wing and the electronics. Multiplying the lever arm by the force gave the righting moment of the boat (5.88 Nm).

Therefore, it was established that the boat must not encounter heeling forces that would create a heeling moment greater than (5.88 Nm). To calculate the heeling moment, the highest conceivable force of 25N , at he the highest allowable heeling angle of 20 degrees was used to find that the heeling moment was 5.65Nm, less than the righting moment, indicating that he boat would remain stable.

This simplified calculation was used only as an indicator and an approximate estimation of stability. In reality, the forces on the sail will vary greatly, and a number of other parameters come into effect, including the spill of air off the wing. In the world of boat design, the quest to accurately estimate stability is ongoing. However, this simple calculation is sufficient to allow for the progress of the design stage.

Computer Modelling

Once the dimensions for the wing were set, and the some simple calculations were performed to ensure that the boat would remain stable with the specified dimensions for the wing, the next step involved using several computer software packages to draw, analyse and model the wing before fabrication.

The NACA 0012 airfoil was generated using the Profili v1.2 [3] software package. This programme contains a searchable database of over 2000 airfoils. With Profili, it was possible to generate NACA airfoils and modify the camber, thickness, chord length and other dimensions. A drawing of the NACA 0012 airfoil was generated using this software and exported as a .DXF file.

"DesignFOIL" was used to analyse the airfoil. The .DXF file containing the NACA 0012 was imported into the programme and a virtual wind tunnel simulation was set up. The flow was set at an averages wind speed of 5 m/s and the airfoil was set to its optimum angle of attach of 12 degrees to the wind.

A simulation was run in this virtual wind tunnel to determine the centre of pressure of the airfoil and also to compare lift and drag data with the data from

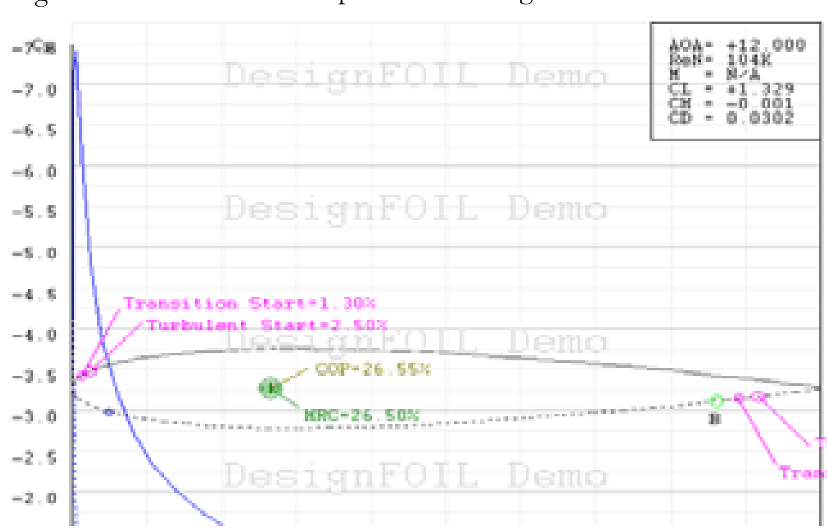


Figure 9: Virtual Wind Tunnel Simulation in "DesignFOIL"

[3] See http:www.profili2.com

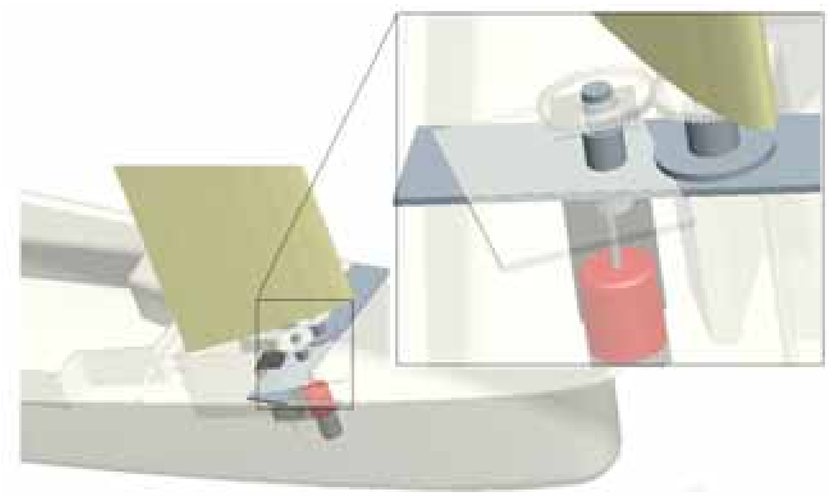


Figure 10: Mechanical Linkage

UCD wind tunnel to ensure its accuracy. Once the simulation was completed, it was found that the centre of pressure of the airfoil was positioned at 26.55% of the chord length (49.12mm).

The centre of pressure of the airfoil was used as a guide for the position of the mast through the wing. By locating the mast at the centre of pressure, the torque required to turn the mast is considerably reduced. This setup is especially desirable since the mast itself is rotated to set the sail.

Finally, the wing was modelled using the "Pro/Engineer" modelling software package. An assembly drawing was created where all the parts, dimensioned correctly, were assembled using this software to ensure there were no dimensional faults are overlooked design flaws.

Mechanical Linkage Design

Once the design of the wing had been completed, a suitable mechanical linkage system had to be design to rotate the wing about the stationary mast.

A small, lightweight DC motor was selected to drive the sail. This compact motor (164 g) had an internal gear ratio of 810:1. This allowed for high torques at low rpm to be achieved. To was decided that the rpm of the wing should remain relatively low, since the wing would not be rotating large amounts at any given time.

The geared "Como Drill 12V DC motor" was a choice to reduce the rpm effectively and efficiently due to its high reduction ratio.

The motor, housed below the deck securely in a waterproofed location used a custom machined aluminium shaft to translate its power. The aluminium shaft had a machined flat surface to which the gear could be slotted over and fixed in place using two grub screws. A spacing block was used to mount the motor to the underside of the deck and to help align the shaft to the axis of the mast.

Two gears were used to translate the motion of the motor shaft to the wing. One of the gears was attached to the base nylon bearing and aligned to a second, driving gear. Power was transmitted to the wing via the gears that were connected to the shaft of the motor.

To allow for the wing to smoothly rotate about the mast, nylon bearings were used. Nylon has very low friction properties and is ideal for applications such as bearings, rollers and carriage wheels. The tubular bearings were machined to specification and glued into the foam wing.

The main reason that the wing was designed to rotate about a stationary mast is due to the fact that wires must run from the wind vane, positioned on top of the mast, down to the control system, located on the deck. If the mast were to rotate, the wires would eventually become tangled and ultimately fail.

The final design consideration concerning the mechanical linkage was to align the gears correctly.

Figure 11: Fitting the model boat with a GPS receiver

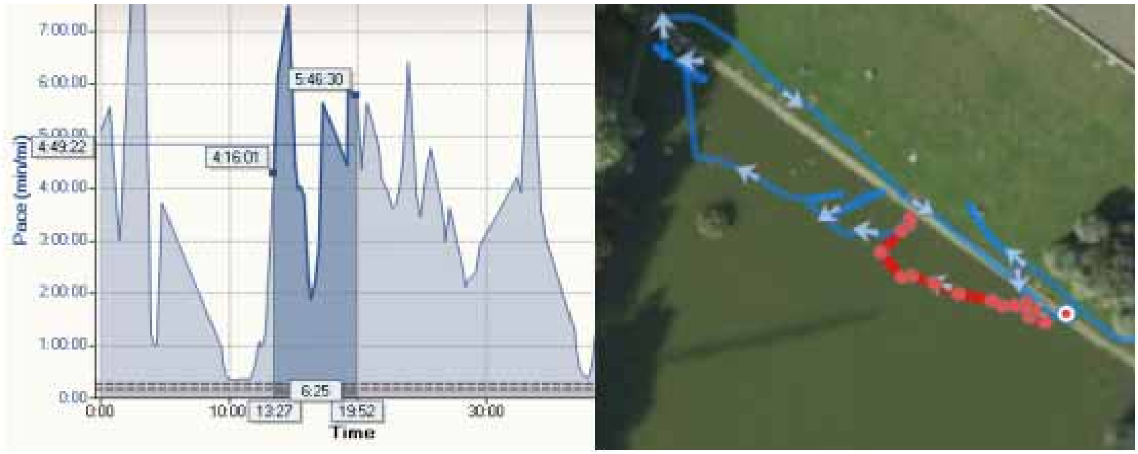


Figure 12: Run #1 with the wind

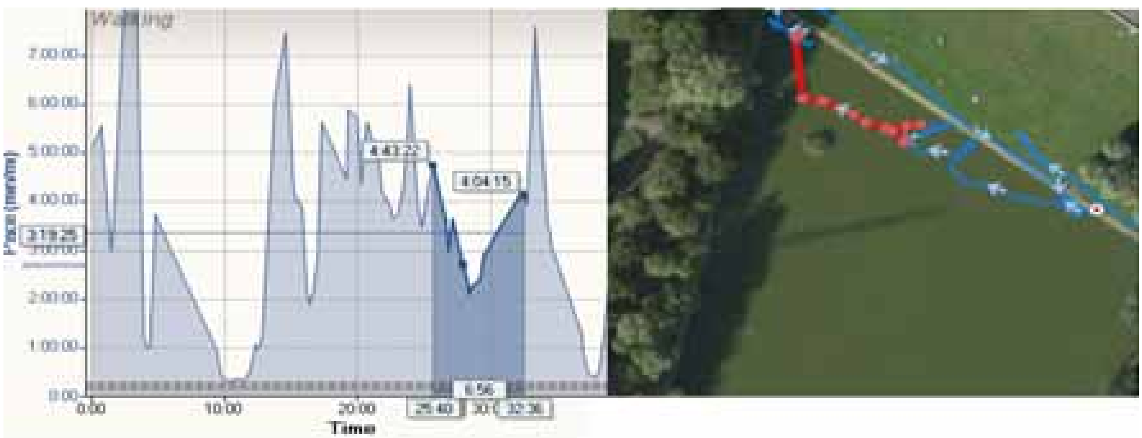


Figure 13: Run #2 with the wind

The design was modelled using the Pro/Engineer software package to see what size gears would best fit the distance from the mast to the shaft. Once this distance was calculated the gears were ordered from an online supplier. A screenshot of the model that was used to help the dimensioning of this design can be seen in Figure 10..

GPS Testing

Once the fabrication stage was completed, the boat was fitted with a GPS receiver. This allowed for the boat speed, course and time to be recorded and graphed. The boat was tested at UCD Lake, where on the day, the conditions were light, with a small, inconsistent breeze.

The GPS receiver collects all of the data and this can be loaded onto a laptop via a simple USB connection. A software programme "SportsTracks" can be used to analyse the data, relate the data to satellite images of the location and plot the pace of the boat during testing.

The GPS receiver plots the boat speed as pace (min/mile), taking the inverse of this value and converting to metres/sec it was found that the fastest time recorded by the GPS receiver was 0.25 m/s.

The graph of pace against time can be seen on the left of Figures 12 & 13. The associated waypoints for each plotted pace can be seen on the right, highlighted.

Interestingly, the highest speed was recorded at the beginning of the run when the wind speed picked up and the boat was set on its course. Again, the local winds were light and in the south-easterly direction, parallel with the edge of the lake shown in the satellite photo.

A similar outcome occurs in the second run with the wind proving the consistency of the wing to perform in the light wind conditions. Examining the same plot of pace versus time it can be seen that the second trough in the graph marks the lowest pace and hence the fastest speed, recorded at the beginning of the second run.

Sailing a Faster Course

Hypotheses from a study of polar performance curves

Part 2 – Finding the Optimal Course to Target

Michael Nicoll-Griffith

The speed at which a human being can move does not increase his happiness, and yet he would experience profound unhappiness if his hopes of increasing his speed were taken from him — C.A. Marchaj

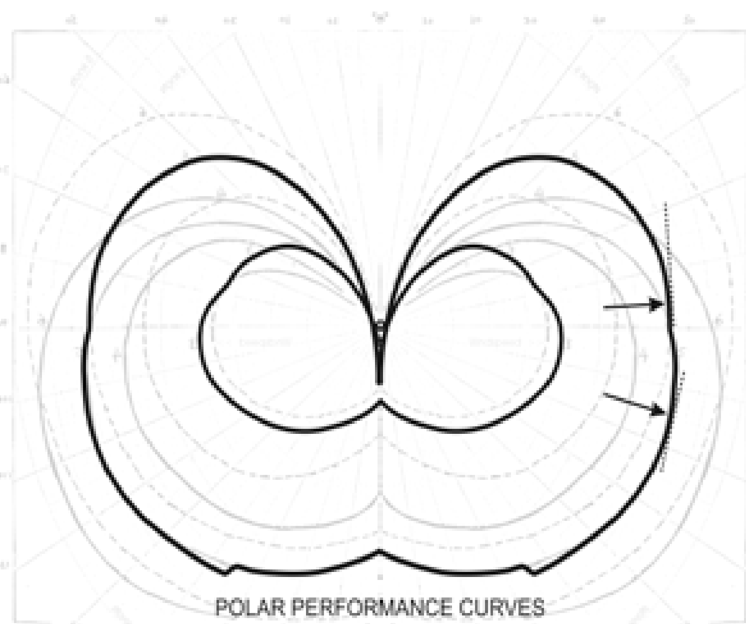


Figure 1 - Tanzer 22 Polar Performance Curve

The term VMG(Target), abbreviated here to *VmgT* "Velocity Made Good in the Target's direction" is sometimes called "*VMC*" (Velocity along the Course") by offshore racers. It is used in this paper to mean the progress made in the direction to a destination target. That could be a harbour, a racing buoy, or to round a headland. From the Yacht Racing Rules, we often might use the word "*mark*". In offshore races or when cruising, there may be no actual object close by, in which case this could be a compass direction. In this material it will be VmgT. The symbol VmgW, by contrast, will be used to designate the speed made good in a windward or leeward direction – which means up or down the wind ladder.

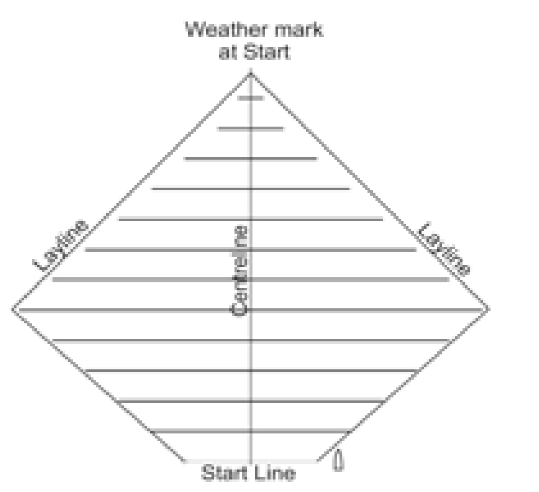


Figure 2 - WIND LADDER

The wind ladder

Firstly, we need to get on the same level of understanding about the traditional method of assessing angles to sail. By the end of this writing, you will probably agree with the author that the idea of a wind ladder as a measure of sailing progress is conceptually flawed, and the basis of much misunderstanding. However, it serves as a good starting point to get us all thinking in parallel.

Being a ladder, it has rungs. Since a boat has to go upwind by tacking, she can allow herself to get to the so-called *lay-lines* but not go beyond them, the rungs are wider in the middle than at the ends. Because such a boat can sail on the port or starboard tack, the left and right displacements can be accommodated without cost.

In Figure 2, assume we are proceeding up to a weather mark exactly to weather of a starting line. Now let us say this defines a "centreline" in the prevailing wind. The course is symmetrical left and right. We can go off on starboard leaving the centre of the starting line behind. If we go all the way to the lay-line, then, when we tack, the mark is on the "return" path. It points us to the mark. If there is any cross-current or an unexpected variability in the wind, then we may overstand or miss the mark, and possibly have to take two tacks at the end.

If we are going downwind, then our progress is measured by how fast we are moving from one rung to the next lower. In this case, the essence of the challenge is to get downwind as fast as possible. The same general arguments apply as in going upwind.. Again, the left and right components take care of themselves if the boat switches tacks at appropriate moments.

What has this got to do with the polar curves, and how do we integrate the two charts?

Enter the Polar Curves

In the context of the cusps discussed in Ah-ha #1, let us apply knowledge gained from the polar curves. We will use here the Tanzer 22 polar curves since these have two types of purity in them. Firstly, they were measured, not calculated by a computer program. Therefore they have not suffered from computer short-cuts or assumptions made by the programmer. Secondly, they were developed without any marketing orientation or game-playing goal, such as the curves used in the recent Volvo Ocean Race Game.

Upwind

The polar curves of Figure 1 show that the optimum heading angle for a Tanzer 22 tacking upwind is 46° in a 5 knot wind. Her velocity will then be 2.85 knots and her *VmgW* will be just a touch over 2.0 knots. Figure 3 "Best Upwind Angle" highlights this detail extracted from the main chart. (See Figure 3).

The 46° is the best angle to sail upwind, and is determined by the horizontal line T-T. In geometry, it is called a *"tangent"*. This line T-T just touches the polar speed curve at the most-upwind place for a boat aiming to sail against the wind. That sets the point A to which the boat should aim. Points to the right of A will mean the boat goes faster into a more

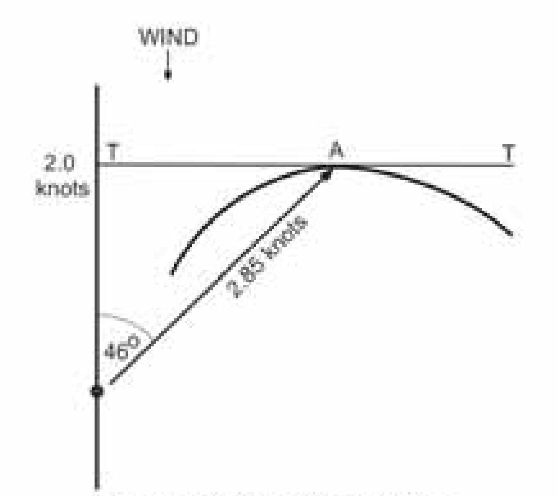


Figure 3 - BEST UPWIND ANGLE

remote place, while points to the left mean the boat is “pinching” – heading closer to the wind, but moving slower.

Boats that go too far right sail faster, but go a too-much-greater distance. Those which “pinch”, go a shorter distance, but go too-much slower. A boat that wishes to make the best speed upwind will head in the direction of point A and achieve the upwind speed VmgW of 2.02 knots.

Downwind

In the case of the downwind cusp, we can again place an horizontal “across-the-wind” tangent to the curves of figure 1. We could then read off that the boat would travel 3.25 knots at an angle of 158°. (See Figure 4).

If she is sailed towards D, then the VmgW (speed made good downwind) will be the maximum of 2.95 knots. We know this is the best VmgW because the tangent line T-T (which is a rung of the ladder) just touches the curve there. See Figure 4.

The target is usually assumed to be directly downwind of the Origin point. Therefore, the boat can come back from D in a sort of mirror image. Again, the boat that goes wider goes faster and farther. The one that holds in goes less distance, but slower.

This is the point at which most analysis of a polar performance curve ends. We still have a long way to go. Are you ready for the journey?

The 22° away from the straight downwind line is called the downwind tacking angle. That is 180°-158°. Boats which can *plane* on a *broad reach* will want to go wider – to deviate more from the straight-down direction. They have larger downwind tacking angles. So these effects will be more significant for them.

It is quite difficult to measure the boat’s angle to the true wind direction, as is required by this exercise. Those on board (and the boat itself) only sense the apparent wind: the way the air reaches the boat. In addition, because the boat is travelling *with* the wind, minor changes of the real wind direction result in a large variability of apparent wind direction. Some boats have wind indicators or instruments that can display True Wind Direction (“*TWD*”). Unfortunately, simpler instruments do not display this. On the boat, it will be easier if these angles have been converted to apparent wind angles, which are relative to the bow of the boat. These are readily read from masthead wind *vanes*.

Values for the optimum apparent wind angles can be calculated and plotted. They are close to 30° (upwind) and 100° (downwind), for the two cases shown. The formula is that for *vector* subtraction. AW = TW - *Vb*. Apparent Wind equals True Wind minus Boat Velocity.

More fully (if you want to set up a conversion spreadsheet), with angles measured in degrees and TWA as the true wind angle off the bow:

AWA = 90 – arctan[(TWS * sin(90-TWA) + Vb) / TWS * cos(90-TWA)]

AWS = sqrt { (TWS * cos(90-TWA))^2 + (TWS * sin(90-TWA)+Vb)^2 }

i.e. Obtain AWA = Apparent Wind Angle, and AWS = Apparent Wind Speed, by supplying TWA = True Wind Angle, TWS = True Wind Speed, and Vb = Velocity (Speed) of Boat.

The functions are standard trigonometry.

Values of apparent wind angles for a Tanzer 22 moving downwind in a 5 knot breeze will be found in Figure A in Part 1. It may surprise you that when the wind comes from exactly abeam (90º), the boat is actually sailing within 40º of dead downwind.

In both the upwind and downwind diagrams above, the line T-T is considered to be part of the wind ladder. However, as we shall see later, this line T-T should not always be aligned with the ladder rungs.

Cross-wind

Now let us consider the reaching cusp that occurs between 80 and 100° from the upwind direction. (See Figure 5, overleaf)

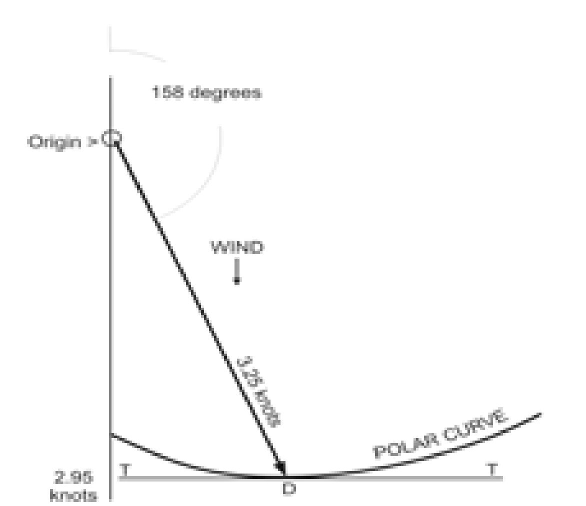


Figure 4 - BEST DOWNWIND ANGLE

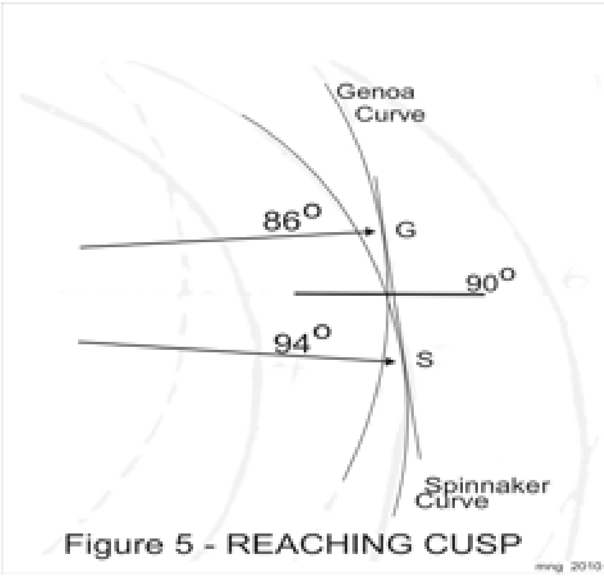


Figure 5 - REACHING CUSP

The reaching cusp is clear of the centreline which is the core of the upwind and downwind cusps. So this cusp is not symmetrical. The two cheeks come off at different angles. Also, these angles vary with wind-speed. Here is a detail of the one at 5 knots. We see the cusp occurs at 90° course angle. (An enlargement of the centre of this figure is Figure 6).

This cusp is similar to the upwind and downwind cases in the sense that sailing in the cusp area is not profitable. However, this one arises from the different characteristics of two sail plans.

Although the intersection of the two curves is very oblique, the angle between the two preferred courses of G and S is as high as 8°. How many of us have sailed in the disadvantaged direction, without being aware of it?

By placing a tangent line across the bulges of the two curves, we can determine the points G and S. These are the points which have the maximum VMG for any destination direction lying between 86° and 94°, given a 5 knot wind. This tangent line does not have any other course-setting significance.

To elaborate: When the target happens to bear between 86° and 94°, the wise sailor sails some with the spinnaker towards S, and some with the genoa towards G. In doing this, he gains in two ways. a) he gains in average speed approximating 0.05 knots. b) he gets an option to sail higher or lower by 4° either side, and can put himself in better wind conditions, at no cost in distance covered.
(See Figure 6).

In choosing which *head-sail* to pick, the helmsman may bear in mind whether the spinnaker or genoa will be most useful at the end, whether he wishes to sail low or high for wind or current reasons, and the effort needed to change the sail plan.

This is the equivalent of selecting the preferred tack when going up-wind and down-wind. i.e. that he makes the choice which heads him closer to the target, or into more favoured waters.

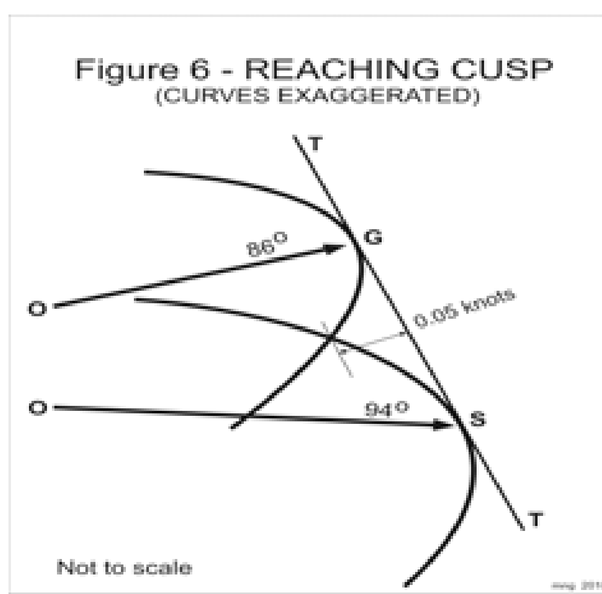
Many shorelines have bays and promontories. When sailing in a river with current or in an estuary with tides, this reaching option can put the boat into eddy currents in each bay. This can win races. This way of using a cusp also assists sailing windward or leeward "circles" and gaining distance. But don't get confused by the terminology. These are not circles! When changing courses, make the change an 8° angle!

Stuart Walker, in "The Tactics of Small Boat Racing", page 188, gives an illustration but this only applies for boats on a beat.

The geometry of these cusps varies significantly with wind-speed. Notice on the main polar diagram of Figure 1 that the cusp when in 3 knots of wind is near 75°. In 4 knots wind, it is at 80°, and at 6 knots, close to 100°. This is summarized in Table 1-1.

At higher speeds, the polar curves tend to be more circular because hull speed is limited on displacement hulls. Therefore the cusp lines will intersect at shallower angles. The importance of avoiding bad sectors is thereby greater at lower wind-speeds.

Figure 6 - REACHING CUSP
(CURVES EXAGGERATED)



Windspeed (knots)	Cusp centre (degrees from True Wind)	Low limit "G" (Genoa)	High limit "S" (Spinnaker)	Speed gain at mid-cusp (knots)
3	77	70	83	0.08
4	81	75	84	0.06
5	90	86	94	0.05
6	100	95	104	0.03

Table 1-1 Cusp Limits

Crossing the Wind

Regardless of whether a boat is sailing upwind or downwind, it has always been taught that courses can be preset for sailing out to the side until the *tack* or *gybe* point, or a new wind comes in. The books claim that it doesn't matter where the tacks are made because all of the lines in Figure 2 are at right angles. But, in fact, as soon as the boat leaves the centreline as origin, the diagram is no longer valid! *A boat that sails across the wind changes the geometry of the race course as she does so.*

Shedding the ladder

First off, let's return to the up-wind / down-wind ladder. We will see that a feature of the ladder is that, as the boat moves out to the side, it becomes less and less relevant.

Before participation in the Volvo Ocean Race Game, I used to teach that beating upwind was simply a case of going to port on the best upwind angle and then to starboard on the reverse, mirrored, upwind angle. (It could equally be starboard first). The sailing textbooks I owned confirmed the symmetry and "right-angleness" of this. (See Schult, "Tactics and Strategy in Yacht Racing", page 85).

Respected authors (A detailed list and discussion is in Section 6 "Differing Opinions") wrote specifically and repetitively that within the lay-lines one should sail up the *windward* ladder. Wind shifts could alter this by twisting the polar curve to fit the new wind. (Walker, "Wind and Strategy", page 387). For destination targets lying outside the lay-lines, they wrote that one should sail straight towards them. That made me uncomfortable. My discomfort arose because this implied an abrupt transition from the upwind model to the reaching model as the boat reached a layline, an arbitrary point. There would have to be a sudden change in philosophy as the lay-line direction was passed.

This is just not reasonable.

The Ladder meets the Polar target

Upwind

The extreme case of difference between the ladder and the target occurs on a lay-line. A boat sailing on starboard tack on the starboard lay-line will be moving upwind at the normal rung rate, and 100% of her speed is devoted to getting towards the target. Thus, Vb = VmgT.

In Figure 7, we can see that immediately before she tacked at point L, she was still moving upwind at the normal rung rate, yet 0% of her velocity was devoted to approaching the target. In other words, the final seconds of her *port tack* could be considered totally non-productive. What was she doing? She was merely "getting into position." Indeed, if the wind is variable, then this confidence-building activity may turn out to be a total waste. It is this waste at the laylines that the author believes can be saved by sailing in dynamic directions.

The ladder rungs which were taught to us as straight now must be replaced by circular rings, centred on the destination. These define the target; as a target. The rings are circular. They have no

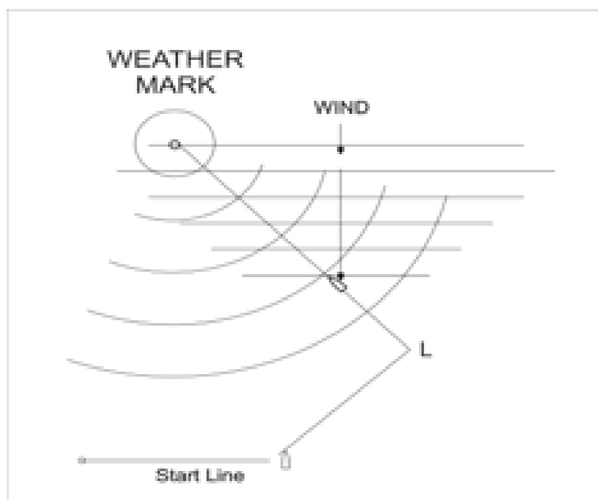


Figure 7 - STARBOARD APPROACH

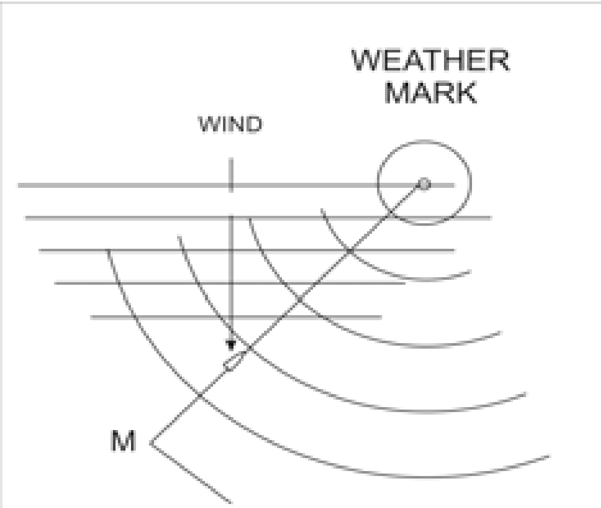


Figure 8 - Port Approach

relationship with the wind direction. In a course race, at the centre of an upwind start line, the rungs and the rings are equivalent, but not thereafter. Indeed they start diverging immediately the boat goes off to the side. They continue to diverge as the boat moves away from the centreline all the way out to the lay-line.

If our helmsman is to cross the rings most effectively it will mean him tracing some part of a spiral path. Should he then be sailing upwind along spiral arcs? For faraway targets, the spiral would be larger and looser. If the target is closer, then the circles and spiral will be tighter. Potentially we may need to take an extra tack or two, but this is not at all certain.

When you actually head in a direction that is to the left or right of a destination target, the angle at which you should sail to get the best VmgT continually changes by a small amount.

Most sailors recognize that, in any long distance race, the wind direction will change significantly between "now" and the end of the race. In the context of these changes, being closer to the target can really pay off, and often is more important than being "further upwind". Being further upwind may be a delusion. Getting closer to the target is real.

This perspective on the angle to head leads to another point. The upwind and downwind cusps are only symmetrical in a static sense; while the boat is on the centreline, at the start or at the target. They cannot be used as symmetrical elsewhere, when the boat is to one side or other of the centreline. It is incorrect to treat the polar performance curves as mirrored curves when the wind and the target are not aligned. The "best course" angles cannot be used in the manner often assumed, as matched opposites. We will now examine this.

Why is it that the close-hauled course, shown in Figure 8 as on the port lay-line, which appears to be the best route, may not be so? The target is on the symmetrically mirrored line, and that seems "obviously" to be the best route. But maybe it isn't. There are precedents. Kingston, Ontario is south of London, yet the initial heading you take to get there is 279°, which is North of West. Here, to cross the rings most quickly we must get the best VmgT — we will make more progress towards the destination target if we lay off from the position shown and foot back towards the right side. In part 4 of this presentation, we develop the numbers mathematically that illustrate this.

No longer can we honour the rungs of the ladder at right angles to the wind as the measure of the best course. Instead, our tangent to the polar curves must be set at right-angles to the direction we want to go - the tangent must align with the rings.

Let us look back to the polar curve now. Since the polar curves are oriented with the wind direction, the amount of the slant of the tangent T-T will have to equal the angle between the wind direction and the target's direction.

The diagram of the port layoff (Figure 9) now shows the new tangent. The tangent which used to touch at A, is replaced with one touching at B. We are now starting to take recognition of the direction to the destination.

Therefore, having tacked onto port, our boat must now aim for B. Sailing at this lower angle, the

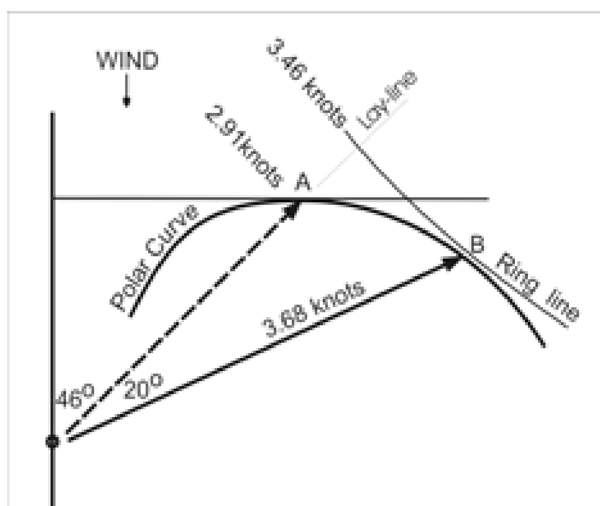


Figure 9 - PORT LAYOFF

boat's velocity is increased to 3.68 knots. The velocity made good towards the target increases to 3.46 knots, a gain of 0.55 knots, or 19%.

There are some things to notice in Figure 9.

The tangent has been rotated by the angle between the wind and the target. It also has ceased to be a straight line. Of course, it is a target ring! The ring, although curved, still fills the role of the tangent. It tells us the new angle we must sail for maximum VmgT to the target. So, indeed, we have to head for B.

Since the line through A points at the destination, the ring will intercept the layline at right angles. So the ring where it touches the polar curve at B will be somewhat closer to A than if it were straight. It will however be straight if the target is a direction, or located at infinite distance.

As we get closer to the target, the rings will have smaller diameters and therefore the contact point will tend to move away from B, closer to A. This second order correction might add "distance to the target" as a fourth input factor after "the angle between the wind and the target". It could cover the spiral element in our simple curved track. That might suggest a second-order adjustment, but actually is one that only becomes necessary if we cannot steer precisely enough.

We will be moving across the *windward leg* until, as we reach the centreline, the aiming point B will be at A and then move to the other side of it. Therefore the boat will have to gradually tighten up as she aims for an upwind target, if she is to continually maximize her VmgT.

Is it reasonable to suggest that coming only to the layline at M in Figure 8 might not have been enough? Does the geometry suggest we should have "overstood"? Or would it have been better to have tacked sooner, when we were more "underneath" the target? This will have to be decided! We can wonder whether what was a lay-line is indeed still a lay-line with this new assessment. One thing is certain, and that is that the rungs of the ladder have ceased to be of primary interest.

Finally, the reader will appreciate that, as we headed towards the tacking point at M in Figure 8, on starboard, we should have tightened up on our angle. That's because the tangent to the velocity curve T-T, which used to be horizontal, then needed to be slanted right to become a ring line centred on the target, as the lay-line was approached. .

In Part 3, we will move forward to consideration of the whole weather leg and the whole downwind leg. We will also examine the work of existing authors, and surmise how they might have become misled

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Revised to 10 04/28 ©mng@kingston.net

Glossary

AWA Apparent Wind Angle. The direction, measured from the boat's bow, from which the wind comes.

AWS Apparent Wind Speed. The wind speed experienced by someone on board. Increased when going upwind, and reduced when going downwind.

Lay-line That line which a boat, sailing on her best upwind or downwind angle would just "fetch" the target. The line of the last track to an upwind or downwind mark.

Ring Line A circle around a target that can be used to explain progress towards the target.

TWA True Wind Angle. The angle between the heading of the boat and the direction of the actual wind.

TWD True Wind Direction. The direction from which the wind is coming. Independent of the boat, it is usually based on a magnetic compass.

TWS True Wind Speed The speed that would be felt if the boat was stationary.

Vb The speed or velocity of the boat, measured in knots, or nautical miles per hour.

Vector An object that has magnitude and direction. e.g. Wind vector, Current vector.

VMC Velocity along the Course. Effectively the same as VmgT, but a term usually used in offshore racing, where sailing is long-distance in directions, rather than to local specific targets.

VmgW Velocity (made good) measured up or down the wind, as in the wind ladder.

VmgT Velocity (made good) in the direction to the current target.

References

[2-3] Joachim Schult "Tactics and Strategy in Yacht Racing".. Nautical Publishing Company 1970

[2-4] Stuart Walker. "The Tactics of Small Boat Racing". Hodder and Stoughton, 1966.

[2-5] Stuart Walker. "Wind and Strategy." W.W. Norton and Company, 1973

Variable Geometry Hapa

Roger Glencross

Every sailing craft has a speed envelope, which defines its performance. In order to improve its performance it is necessary to ascertain whether the limiting factor is aerodynamic or hydrodynamic. With the Hagedoorn craft I use a parafoil whose airspeed envelope is from 6mph to 10mph. With a heavier pilot the top speed is a little higher. But that is when flown as a glider. Gliders have only gravity to propel them (there are no thermals at sea) and gravity is a weak force, which cannot be leveraged up. But I am flying my paraglider as a kite and wind force is often stronger than gravity. So the paraglider's speed could exceed 10mph airspeed when abused as a kite. The thrust required increases as the cube of velocity so this top speed is soon reached as lift/drag ratio deteriorates and the kite starts to disintegrate. There is nothing I can do with this particular parafoil to increase its speed envelope beyond that.

Hapa

Each hapa also has its own speed envelope. A hapa with a large area will be able to start successfully from slow speed but will quickly reach its top speed in a given wind due to increased drag. A small hapa will theoretically have a higher top speed but will never achieve it because it will not produce sufficient thrust at low speed to prevent leeway, so the air kite will have insufficient apparent wind speed and will not take off.

A Hagedoorn craft using a paraglider will never be a high-speed craft due to the very limited speed envelope of the paraglider, regardless of the hapa it uses. If a high-speed hapa is used with a paraglider, (which is a low speed machine) they will be incompatible. Neither will be able to achieve the course that the other can achieve. My low speed paraglider needs a low speed hapa, happily already built by Fred Ball.

A high-speed Hagedoorn craft requires a rigid winged high performance glider. But high performance is not my aim. I only wish to extend the range of true wind speeds in which the equipage can fly manned. This is achieved by increasing the range of courses that the machine can travel. This requires that the amount of thrust from the hapa should be as required on each course and speed. This must be done automatically as the pilot is fully employed flying the paraglider. He cannot see the hapa, which is submerged and somewhat behind him.*

When the machine is taxiing for takeoff the hapa travels slowly at first and therefore only produces a small amount of thrust per square foot of hapa area. Thus, a larger hapa area is needed when going slowly than when travelling faster. The amount of hapa thrust that is required can be assumed to be more or less constant at all hapa speeds. This is because the weight of the paraglider and pilot remains constant, therefore the amount of paraglider lift to permit flight remains constant (there is no desire to soar), and since the paraglider's lift/drag ratio can be assumed to be fairly constant, the amount of aerodynamic drag remains fairly constant. The aerodynamic drag down the hapa line equals the hapa thrust up the hapa line (action and reaction are equal and opposite).

* ["He cannot see the hapa, which is submerged and somewhat behind him." *I will ask Roger to explain this pointwith a diagram, as it's not entirely intuitive. Normally a paraglider pilot, and the paraglider itself face the same way – into the apparent wind i.e upwind. Attached to a hapa, that hapa would also be upwind of the paraglider, so the pilot ought to be able to see it when stationary. When moving, especially at the low speeds Roger envisages, one might expect the paraglider simply to cant (bank) not rotate. – Editor*]

In fact it is a bit more complicated than that. The paraglider lift referred to is actually the vertical component of the paraglider's resultant lift. The paraglider will fly slightly banked in order to give horizontal force like a sail. But the angle of bank is small so the excess of resultant lift over vertical lift is small. I only need a small amount of horizontal sail force because I am quite happy for the hapa to be pulled along at only 2-3mph water speed. I do not envisage problems with the paraglider sideslipping (it has no centrifugal (or is it centripetal?) force to balance it because it is flying in a straight line). A twin-engined aeroplane with one engine out of action can fly in a straight line while slightly banked by engaging the rudder. The vertical panels at the paraglider's wingtips are in effect rudders.

If the amount of hapa force up the hapa line is 'wrong' for the desired paraglider speed and course, the equipage will be prevented from going on the speed and course that it desires. So the need for a variable geometry hapa producing constant thrust at variable hapa speeds is established.

The lift formula for the hapa is:-

$$L = ½.C_L.\rho.S.V^2$$

That is:

Lift = One half of the product of: Co-efficient of lift x water density x hapa area x velocity^2

Lift coefficient is non-dimensional i.e. just a number; but the remaining units have to be consistent. In the US, lift is in pounds, density is in slugs/ft^3, area is ft^2, and speed is ft/sec. Under the metric system, lift is Newtons, density kg/m^3, area is m^2 and speed is m/sec.

C_L is largely a function of angle of attack. For the large, low aspect ratio, hapa and foil section that Fred Ball has built C_L will never be far from unity. I prefer to work in US units, so as water density is approximately 2 slugs/cu ft so the lift formula is can be simplified:-

$$L = ½ \times 2 \times SV^2 = SV^2$$

These formulae assume that hydrodynamic flow is two-dimensional. In fact it is three-dimensional, i.e. it is vortex generated. The development of simple formulae to demonstrate three-dimensional flow should be the subject of an AYRS prize. It is as important as that. The absence of these formulae is a major impediment to amateur research. The two-dimensional formulae are more parables than truth.

How can the quantity of hapa thrust be controlled to keep it constant as hapa speed varies? Let us look at the various components of the lift formula. Control by means of adjusting C_L means adjusting the angle of attack. Unfortunately, a foil has a 'natural' or 'best for L/D ratio' angle of attack (small and critical for a high aspect ratio foil, say 2°, larger for a low aspect ratio foil, say 4°). Any attempt to alter this, especially in a high aspect ratio foil is doomed to failure. Any attempt to reduce the angle of attack below the 'natural' results in a luff, in which the foil merely drags along at nil angle of attack like a flag, producing no lift. Any attempt at increasing the angle of attack above the 'natural' results in a severe deterioration in the lift/drag ratio (which is pretty marginal in the first place and permits only very limited courses to be flown) followed by stalling in which most lift is lost. So playing around with the angle of attack appears to be a non-starter.

With regard to water density, this alters with depth, temperature and salinity, but not sufficiently to be of any practical use.

So the only solution left is variable geometry of the working hapa area. This need not necessarily mean that the hapa has to change its area. It could rise increasingly out of the water at speed i.e. be a ladder foil as per WILLIWAW.

By how much must the hapa area alter? Let us assume that the kite can tow the hapa from 2mph to 10mph ground speed. Below 2mph is problematical. The theoretical hapa area required is huge. The most efficient foil in the world produces no lift when stationary, and not much lift is produced when going very slowly since the water has to 'notice' the force put on it, due to its viscosity, before the foil starts to work. So I will wing it for the first 2 mph e.g., use an anchor.

The weight of the equipage is as follows. (The weight of the hapa is ignored because it floats).

	lbs	
Pilot	145	
Undercarriage	35	
Parafoil (dry)	10	
A mast	10	
Total	200	lbs (about 91kg)

The undercarriage is a Campari Catapult dinghy less centreboard, rudder mast and bowspirit. If its trampoline produces lift or ground effect that is an added bonus. I have always dreamed of building a biplane, the most compact of fixed-winged aircraft,

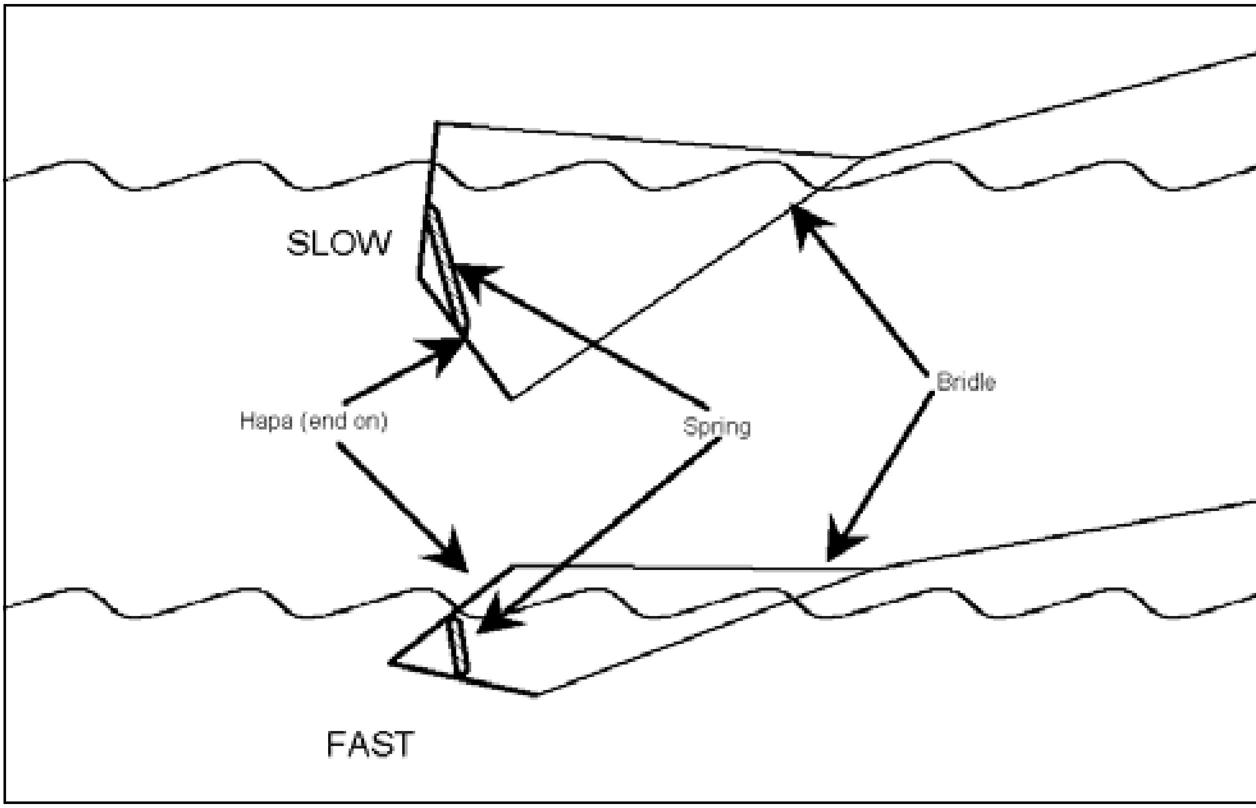


Figure 1 - Folding hapa

but I was put off by the loss of lift caused by the interference effect of one wing on the other. But these two wings are so far apart (19ft = 5m minimum) that there will be no interference.

The kite has 28ft (8.5m) wingspan and the trampoline beam is 6 ft 6 inches (2m). Flight height is 2 feet (60cm).

The lift equals the weight of 200 lbs (no soaring is expected); lift/drag ratio of the aerodynamic part is estimated at 3 to 1, so drag is 200/3 = 67 lbs. So the hapa's lift or thrust must be 67 lbs at all times. The hapa line will not be horizontal but will be so near to the horizontal as to make little difference.

When travelling at a water speed of two mph (2.934 ft/sec, slightly less than 1m/sec) we get:-

$$\text{Lift (67 lbs)} = \text{S} \times 2.934$$

$$\therefore \text{S (Area)} = 7.78 \text{ sq ft } (= 0.72 \text{ m}^2)$$

When travelling at a water speed of 10mph (14.67 ft/sec, about 4.5m/sec) we get:-

$$\text{Lift (67 lbs)} = \text{S} \times 14.67^2$$

$$\therefore \text{S (Area)} = 0.31 \text{ sq ft (about } 0.03 \text{ m}^2)$$

So the hapa needs to be able to change its working area from 7.78 sq ft to 0.31 sq ft.

Brassieres

On the BBC Radio 4 programme "The Material World" recently they referred to a bra material that, when it felt a weight, became smaller. When the weight was taken away the material became larger. This was used to give the required amount of uplift when sagging occurred. I have given this matter a great deal of thought. For use on a hapa the material used would have to be heavy duty. Is there such a material available?

Another notion would be a spring-loaded hapa made up of two foils hinged together. (Figure 1). The two halves of the hapa would move closer together when under a strong pull, thus reducing the hapa's projected side area, and open out again when the strain on the line is reduced.

But the spring would be very draggy and would best be hidden within the hapa.

Another idea would be a sliding shut door-type hapa (Figure 2)

When under pressure side B slides into side A. I cannot even envisage the mechanism that would work such a machine.

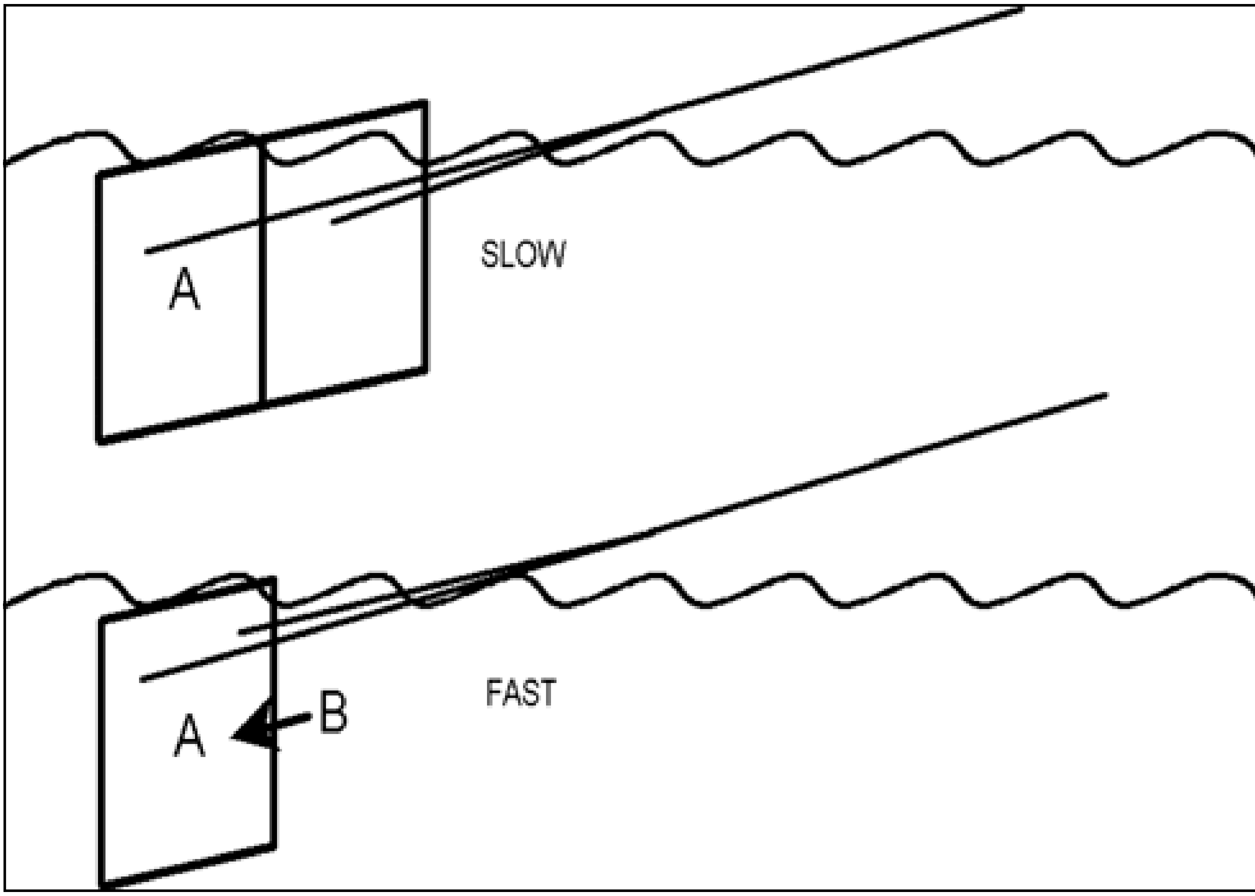


Figure 2 - Sliding hapa

I fear that the successful Hagedoorn craft depends on the invention of the variable geometry hapa. Without such a hapa the craft is very restricted as to which courses it can travel on and in what wind range. Coupled with its inability to change tack unaided it may remain a curiosity, as sailboarding did until inexpensive wetsuits and sailboard schools came along. No doubt flying would have also gone that way had the internal combustion engine not been invented. Tack changing (or shunting actually, the hapa is a proa) entails the pilot landing on the water, the load being taken off the hapa line, an assistant motoring over to the hapa and altering the towpoint on the hapa from fore to aft, and the pilot then taking off on the other tack!

Automatic hapa tack-changing merits an article all to itself. Suffice to say that moving the hapa towpoint while under way requires great force because it is under load and has to be moved, as it were, 'uphill'. The only sources of force available on an unengined craft are wind-power and man-power. One could have two hapa lines that the pilot moved alternately, but he does not have his hands free, and would he have the strength? Also, the two lines could entangle each other.

The force of the wind could be employed by cleating the hapa line at the hapa at both the left and right tack tow positions say, four times, thus giving four tack changes before he runs out of rope. On changing tack, the line is released from the cleat by the pilot pulling another line (more tangles!)

I ask for help from AYRS members on both the constant-lift hapa and the autonomously tacking hapa. At best I am hoping that some yachtsman more conversant with rigging than I am will be able to help. At worst this article gives the lie to the belief that there are no sailing projects within the reach of members. The above would make an excellent retirement project or, more likely, a lifetime project.

Roger Glencross

Catalyst Calendar

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

October 2010

16th – 22nd Weymouth Speedweek
Portland Sailing Academy, Portland Harbour, Dorset UK. See www.speedsailing.com.

20th *Speedsailing* – AYRS Weymouth meeting
19.30 for 20.00hrs at the Royal Dorset Yacht Club, 11 Custom House Quay, Weymouth. Location Map: www.rdyc.freeuk.com. Contact: AYRS Secretary, BCM AYRS, London WC1N 3XX; email: office@ayrs.org

November 2010

6th *Your Projects* – all-day AYRS meeting
9.30am to 5pm, Thorpe Village Hall, Coldharbour Lane, Thorpe, near Staines & Chertsey
Bring your lunch - tea and coffee available. Donations invited to pay for the hall. Details from Fred Ball, tel: +44 1344 843690; email frederick.ball@mypostoffice.co.uk

27th NW UK AYRS Group Meeting
12 the Boleyn, Lydiate, Merseyside. L31 9TP. Contact: Mike Howard for details Tel: 0151 531 6256; or email: ecotraction@aol.com

January 2011

7th – 16th London International Boat Show and
13th – 16th The Outdoor Show
EXCEL Exhibition Centre, London Docklands. AYRS will be there. Helpers are wanted to staff the stand, sell publications and recruit new members. If you would like to help (reward: free ticket!) please contact the Hon Secretary on 01727 862268 or email office@ayrs.org

29th All-Day AYRS Meeting
9.30am-4pm, Thorpe Village Hall, Coldharbour Lane, Thorpe, Surrey (off A320 between Staines and Chertsey – follow signs to Thorpe Park, then to the village). Details from Fred Ball, tel: +44 1344 843690; email frederick.ball@mypostoffice.co.uk

29th AYRS Annual General Meeting
4pm, Thorpe Village Hall, Coldharbour Lane, Thorpe, Surrey (as above). Details from the AYRS Hon. Secretary tel: +44 (1727) 862 268; email: secretary@ayrs.org
Note: Items to be considered by the AGM, including nominations for the Committee MUST be received by the AYRS Secretary before 22nd December 2010 (post to AYRS, BCM AYRS, London WC1N 3XX, UK, or email: secretary@ayrs.org)

February 2011

TBA AYRS Southwest UK Area Meeting
Details from John Perry, phone 01752 863730 email j_perry@btinternet.com (note the underscore in email address).

March 2011

TBA AYRS North West England Group meeting
Contact Mike Howard for details: Tel: 0151 531 6256; e-mail: ecotraction@aol.com

April 2011

17th Beaulieu Boat Jumble
The National Motor Museum, BEAULIEU, Hampshire, UK. AYRS will be there!

29th – 8th May Liverpool Boat Show
Albert Dock Liverpool, UK. See www.liverpoolboatshow.com.

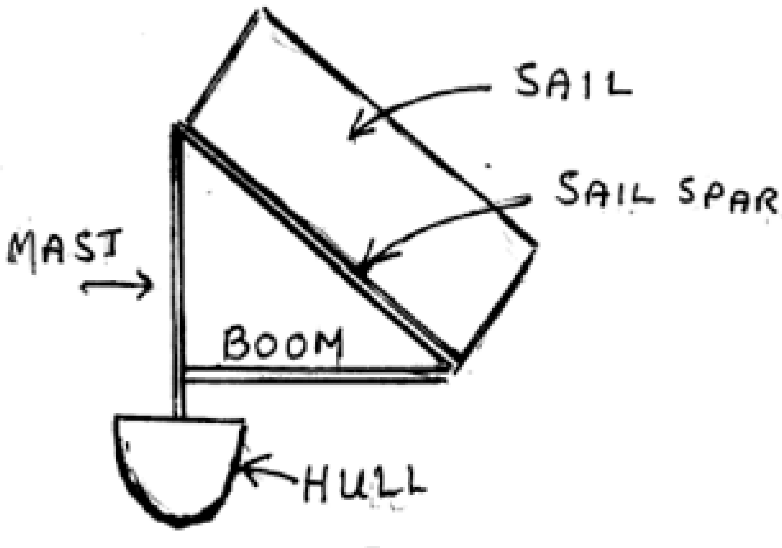
May 2011

TBA Boat trials, Weymouth
Location to be determined. Contact: Norman Phillips email: wnorman.phillips@ntlworld.com; tel: 01737 212912.

27th – 30th *Broad Horizons* – AYRS Sailing Meeting
Barton Turf Adventure Centre, Norfolk UK, NR12 8AZ. Contact AYRS Secretary AYRS Secretary, BCM AYRS, London WC1N 3XX, UK; email: office@ayrs.org. Note: All boats limited to 1.2 metre max draft!

27th – 30th UK Home Boat Builders Rally – Norfolk Broads
Barton Turf Adventure Centre, Norfolk UK NR12 8AZ. Joint with the above. For details see http://uk.groups.yahoo.com/group/uk-hbbr/

Development of the Morley Tethered Kite - Errata
Page 7 of Catalyst 38 was corrupted on its way to the printer.
The correct text is here.



The Morley Kite Sail (from Catalyst 33)

The proposed system, therefore, reduces heel to negligible values, provides for a substantial increase in sail area, reduces hull drag to negligible values and also provides for the rapid transformation to a single sail conventional rig.

Contribution of this Project to Nautical Science

The successful development of Dr. Morley's Kite Sail System will, in the first place, prove the practical application of his theoretical work. In the long term, it will provide an alternative sail plan to the current conventional small boat sail systems. The benefits of the Morley Tethered Kite Sail System is that it significantly reduces the heeling effects, which in turn, provides a safer, more stable and less tiring environment for the sailor. In addition, the system provides increased boat speed by producing lift, which reduces both the wetted surface area and drag.

one metre, have been built, with radio control of the sail setting. These models have been tested on Southport beach in the presence of a steady westerly wind (wind blowing from seaward across a clear area of tidal sandbanks/shallow water). The models behaved as predicted.

Arrangement of the Morley Tethered Kite Sail System

The basic design has been fully described in articles published in Catalyst issues 14 and 33 [Refs 1 & 2]. These articles show a possible arrangement with variable geometry, which can be utilised either as a conventional rig or in the form of a tethered kite sail. The former rig has some advantages when close manoeuvring is required. The kite sail can be set when in open water.

In order to deal with fluctuations in the direction of the apparent wind, the sail assembly is free to rotate about the mast. It appears that this is the first time that this arrangement has been proposed. In order to deal with the fluctuations in the apparent wind speed, means are provided whereby the sail automatically spills wind before the lifting force becomes large enough to lift the boat from the water. The design still relies on a conventional keel and rudder combination for course direction and to combat leeway.

Project Objectives

There are five main objectives:

1. To design and manufacture a full scale Morley Tethered Kite Sail System suitable for a medium sized two-man popular class of sailing/racing dinghy.
2. To install a full scale Morley Tethered Kite Sail System in medium sized two-man popular class of sailing/racing dinghy.
3. To carry out sailing trials with the Morley Tethered Kite Sail System, installed in the chosen dinghy, and develop the techniques for handling the rig.
4. To sail the Morley Tethered Kite Sail System dinghy against a conventionally-rigged dinghy of the same class. To monitor the relative boat speed, angle of incidence, and control issues under a variety of recorded wind and wave conditions.
5. Publish the results of the full scale sailing trials in Catalyst.

Important Notice - AYRS AGM, Annual Report & Accounts

1. Due to the delay in publishing Catalyst 40, the 2009-10 Annual Report & Accounts will be published on the AYRS Website **http://www.ayrs.org**.

The printed copy will be circulated with Catalyst 41 (January 2011) which will most likely not be published until after the AGM.

The Editor tenders his apologies, and would be happy to add his resignation.

2. The AGM will be held on **29th January 2011** (see Calendar)

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

On the Horizon . . .

More Howard Fund applications
Experimental platforms
More sources and resources: reviews, publications and Internet sites

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

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