Catalyst

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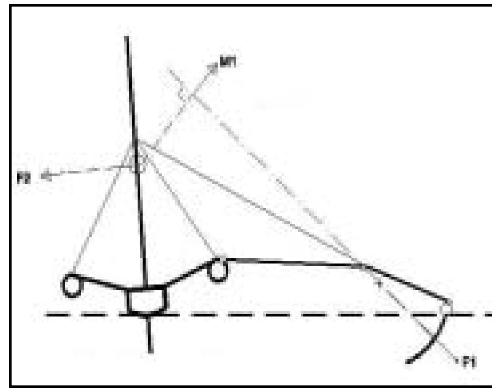

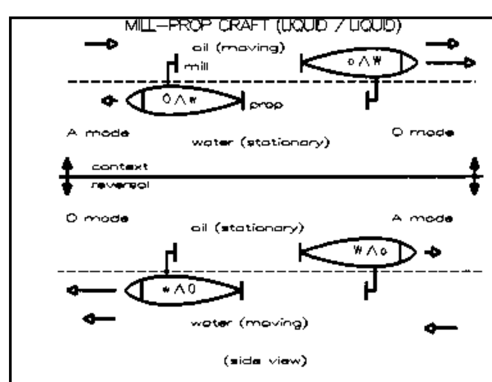

Cover Photo *-still from the video of Giles Whittaker's 24-inch (60cm) HSSC in full flight*

Catalyst

Journal of the
Amateur Yacht Research Society

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This edition of Catalyst has been delayed while the AYRS Secretary has had some major repair work done on her person. It has distracted us a little.

Sorry

Simon Fishwick
AYRS Editor

On an ancient wall in China
Where a brooding Buddha blinks,
Deeply graven is the message
It is later than you think.

The clock of life is wound but once
And no man has the power
To tell just when the hands will stop,
At late or early hour.

Now is all the time you own,
The past a golden link,
Go sailing now my brother
It's later than you think.

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Roger H Strube MD

Down Wind Faster Than The Wind

I'm a new member, or I should say a rejoiner, after what must be 20 years.

As a physicist (or I should say an ex-physicist, now long retired) I took a particular interest in the contributions to Catalyst 12 about Down-Wind-Faster-Than-The-Wind. I was ready to deride the whole notion as smoke-and-mirrors, and was on the verge of picking up my mouse to do so.

Then I re-read Jon Howes contribution more carefully. And then again. He has convinced me that the notion is valid, at least for a low-friction land yacht. It works (and Mario Rosato's dismissal of the possibility, in Catalyst 11, fails) because Howes gets the direction of energy-flow right, taking energy from the fast motion of the craft against the ground, and delivering it to the slower motion of the craft with respect to the wind, using an air-propellor. Using Howes' notation, it's possible (in principle, at least) to get a larger drive thrust T from a lower drag force F, because of this difference between the two speeds; even though the power abstracted from the wheels is greater than the power delivered to the propellor, making up for inefficiencies in the system.

However, Howes complicates the picture somewhat by introducing a moving belt, which increases the level of abstraction and forces more mental gymnastics on the reader; though I can see why he does it, and it is in principle perfectly valid. Readers would probably find it easier to accept a picture of a land-yacht travelling downwind along a stationary surface.

In the case of the land-yacht, Howes has been able to assume that the drag F on the vehicle is entirely available for generating input power P(in) to his power system. Though this might be a fair approximation for a low-friction land-vehicle, it will certainly not apply to a watercraft, in which hydraulic drag on the vessel will be an important factor. It remains to be shown whether DWFTTW will ever be possible for a watercraft.

Jon should be congratulated for a simple and practical tricycle design for his land-yacht. If any vehicle will do the job, it will look very much like that one. At the low (relative) airspeeds that will be involved, the propellor would have to be a large-area flimsy thing. Perhaps what's needed is a radio-controlled model to avoid the weight of a human pilot. I predict it would be the very devil of a steering job to keep it going downwind.

Jon finishes off with the tantalising statement "if the braking losses are very much smaller than the drive + aerodynamic losses it works just fine". Not, you will note, "would work just fine". Did he intend to convey that there existed a real device that had been tested? Or was that no more than an aspiration? I only ask...

George Huxtable, 1 Sandy Lane, Southmoor, Oxon OX13 5HX. tel +44 1865 820222. email to george@huxtable.u-net.com

ROCAT *(See Catalyst 12)*

Here is a long overdue update from ROCAT … I'm very sorry it has taken so long to get in touch.

Hot on the heels of the London Boat Show (where I was encouraged by an extremely positive response to the boat) I took the ROCAT to the Boat, Caravan and Outdoor Exhibition at the NEC, where I discovered that caravaners (who comprised the majority of the visitors to that show) are not generally so well disposed towards exertion!

As you know, I had hoped to get the boat into production this summer ...

unfortunately, I was out of action for a while following the NEC show, and this will no longer be possible. We are now making very good progress though, and will have a production boat on the ROCAT stand at the 50th Anniversary London Boat Show next January, at (its new venue) Excel.

I will keep you posted …

With best wishes
Christopher Laughton
ROCAT Ltd
CL@rocat.co.uk

HAPA STABILISED SAIL CRAFT -

Design Aims and Achievements

Giles Whittaker

Design Aims

From the outset my design aims were to apply concepts from Dr Bernard Smith's Aerohydrofoil (Ref 1) to develop practical fast foil stabilised sailcraft that don't heel, but simply go faster when the wind blows harder.

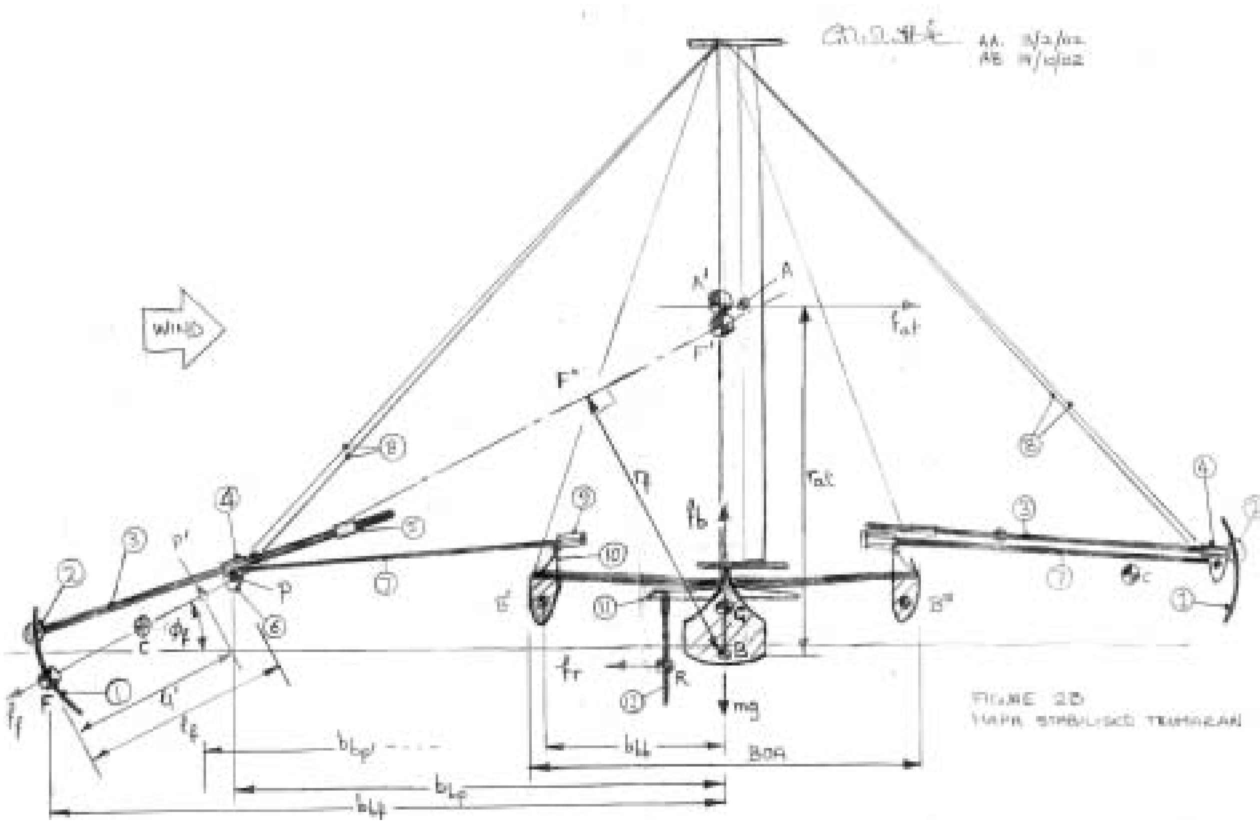
To justify their development, the craft would have to be a significant improvement on state-of-the-art conventional craft on long passages. To do this they must be fast, practical, seaworthy, stable, safe, have good performance at the small apparent wind angles characteristic of truly fast craft, under a wide range of wind and sea conditions including light airs.

Fundamental to achieving these aims, the craft must be inherently stable under a wide range of conditions and on all points of sailing in all three axes:

- Roll, heel, lateral stability
- Yaw, heading, directional stability.
- Pitch, heave, longitudinal stability.

These stability requirements were driven by the decision to develop the craft using models. Once the sail(s) and stabilising foil have been trimmed, only conventional steering must be required to "fly" the boat. There must be no need for an active control system for the stabilising or lifting foils.

I could not keep up, running through calf deep water. An excellent way of getting exercise!



Key

Ref - Name - Remarks

1 - Hapa Foil - Position in its case controls ride depth under load

2 - Hapa Case / Float

3 - Hapa Spar

4 - Hapa Hinge Box - Hapa spar slides through box

5 - Hapa balance weight - Controls static depth of hapa

6 - Aka pod - Streamlined fairing for hapa hinge box

7 - Aka - Anhedral controls aerodynamic heeling moment on aka

8 - Aka guys fore & aft - "Collective, controls aka angle, & heel" "Differential, controls hapa pitch, & ride depth"

9 - Aka Hinge - Sliding hinge

10 - Aka Hinge Bracket

11 - Rudder Stock - Forms anti dive plane

12 - Rudder Blade

B - Centre of Buoyancy - Through which fb acts

A - Aerodynamic C of E - Through which fa acts

A' - Aerodynamic Metacentre - Through which fa and fb act

F - C of E of hapa foil - Through which ff acts ff always acts through C

F' - Hydrodynamic Metacentre - Through which ff and fb act

rf - Righting Moment Arm - Distance of line of action of ff from B'

G - C of G of hull - Through which mg acts

R - C of E of rudder - Through which fr acts

C - see 6. - Through which ff acts

P - Hapa pivot

P' - Effective hapa pivot - Allowing for pivot skew

NHG - Nominal hapa angular gain - Allowing for pivot skew = lf ' / bbp'

Phi f - Characteristic Hapa Angle - Angle of ff to horizontal

RM - Righting moment about B - ff . rf

HM - Heeling moment about B - fat . rat

Net heeling moment is zero when aerodynamic & hydrodynamic metacentres coincide

Hapa dynamic eqilibrium: Hapa rotates about P until ^FCP = 180 deg

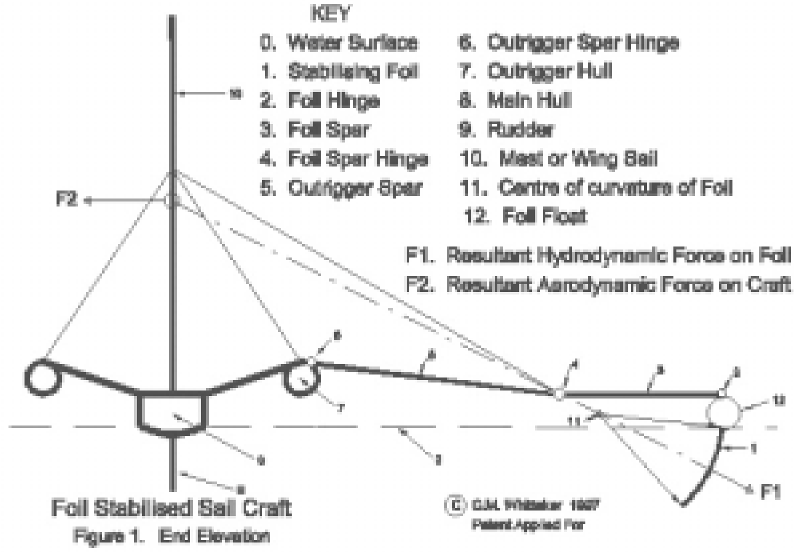
Craft dynamic equilibrium: Craft rotates about B until ^FPA' = 180 deg

Abbreviations

C of C - Centre of Cuvature

C of E - Centre of Effort

C of G - Centre of Gravity i.e. centre of mass



Basic Configuration (Windward foil only shown)

The Problem

Hydrofoils are sometimes used to lift sail craft clear of the water, to resist leeway, and/or to resist heeling to a greater or lesser extent. In 'The 40 Knot Sailboat' published in 1963 (Ref 1), Dr Bernard Smith said that combining lifting and leeway resistance in a deep vee hydrofoil configuration is not a good idea, and proposed a solution with separate lifting foils and a leeway ("drift") resisting foil that also resisted heeling by acting through the craft's aerodynamic centre of effort.

One possible solution is the Bruce foil, a stabilising foil fixed on each side of the craft. The main problem is to prevent its windward foil from letting go of the water, whereupon the craft tends to trip over its leeward foil.

I solved this problem by incorporating a hinge into the stabilising foil system to make the windward foil work in the same way as Didier Costes' "Chien de Mer" (Ref 2) or hapa, and retracting (or removing) the leeward foil. However this created a whole new raft of problems, with a huge number of possible solutions.

The Invention

A stabilising foil (hapa) is hinged to an outrigger (aka). Crucial features include the hinge in the system, the correct curvature of the hapa foil, hapa swing limiters, and the means of stowing the hapas and akas independently. The system has been developed and tested on 10, 24 and 48 inch models. Development is continuing.

Initially I called these Foil Stabilised Sail Craft (FSSC). I now propose to call them by the more specific name Hapa Stabilised Sail Craft (HSSC).

Roll Stability: The limited swing articulated stabilising foil (hapa) (1,2,3) is hinged at (4) to the outrigger (aka) (5) so as to move up and down freely in response to waves and the angle of heel, within predetermined limits.

- The hapa is deployed on the windward side and is the only means of resisting leeway.
- The hapa is dynamically stabilised with respect to ride depth by its geometry.
- Its static depth is set by means of the float or a counterbalance weight on an inboard continuation of the hapa spar (not shown).
- With the craft upright, the resultant Hydrodynamic Force (F1) balances the resultant Aerodynamic Force (F2).
- With the craft upright, the angle of F1 below the horizontal is the **Characteristic Hapa Angle**.
- The angle of heel of the craft can be adjusted by adjusting the stays from the mast to the hapa hinge (6).

Dynamic Stability: As shown in the Figure 2,

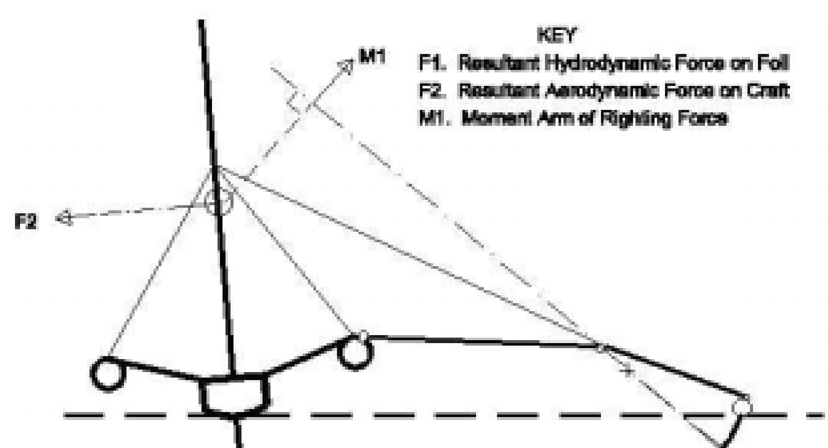


Figure 2. 5 Degree Heel

the craft is heeled 5 degrees to leeward of the dynamic equilibrium position. This small angle of heel creates a powerful righting moment due to the moment arm (M1). This tends to rotate the craft until it is upright when M1 will be zero. This is true for all wind strengths, and also if the craft heels to windward. The change in angle of F1 per degree of heel of the craft is the **Hapa Angular Gain.**
The greater the aerodynamic force, the greater the resulting hapa force, and hence the stiffer the craft. **Gusts blow the craft upright!**

Load Paths: Most of the aerodynamic load is transferred directly to the hapa hinge by rigging in tension, reducing the loads on the hull and greatly simplifying the load paths compared with a multihull.

Directional Stability and Steering: In order to balance the helm, the hapas have to be mounted aft, and must be adjustable fore and aft while sailing in order to balance the helm. It follows that the rudder must be mounted forward, in order for it to be able to steer the craft effectively.

Pitch Stability: The hapa hinge may be skewed so as to stabilise it for changes of fore and aft trim of the craft as it takes off on its lift foils, and in big waves. This arrangement improves resistance to pitch poling, accommodates transition from hull-borne to and from foilborne and accommodates waves.

Hull Stability: The planing hull form used in the HS24 proves to be stable in pitch at all speeds. Unlike many multihulls, there is no tendency to trim nose-down at high speed. The "Viking" bow is an antidote feature to prevent nose-diving in waves, as it is dangerous for solid water to sweep the deck at speed.

Design Achievements: The HS24 and HS48 models indicate the feasibility of my Hapa Stabilised Sail Craft concept. Furthermore, most of the important design features required to make these craft practical have been researched.

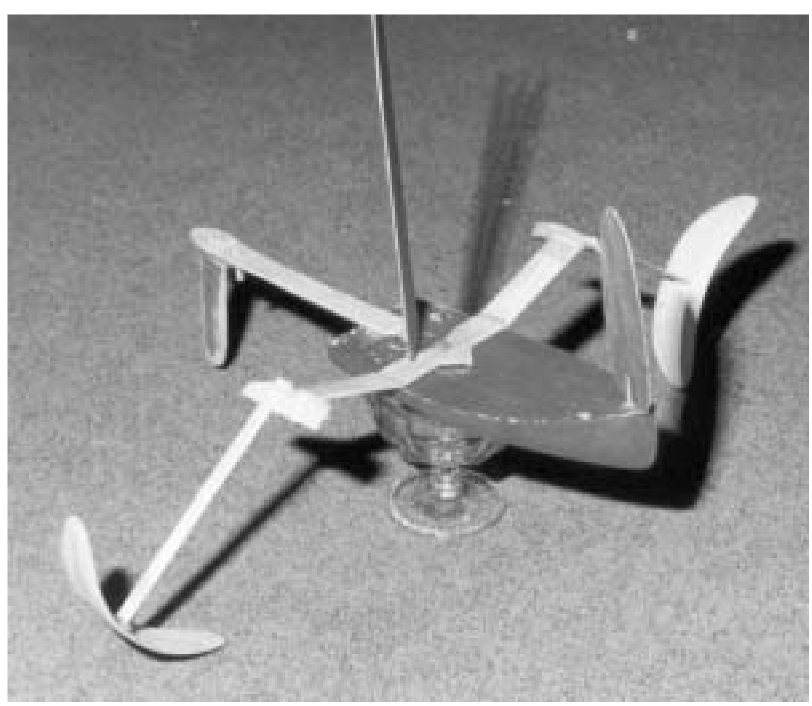


Figure 3. The 10" model with oversize fixed foils planed on a run in strong winds, but could not be prevented from rolling over when close-hauled in waves.

Note the outrigger rudder, that was both ineffective and impractical.

Conclusion

Video of tests indicate that HSSC design aims can be met.

In particular, the hapa stabilising foils prevent heeling, reduce rolling, resist pitch poling, and allow the helm to be balanced for any point of sailing and wind strength.

When **foilborne**, waves pass between the hull and the main lift foil. As a result the rig can be kept powered-up in stronger winds and bigger waves with HSSC than with conventional craft.

Higher speeds will be able to be sustained over long distances with less discomfort and greater safety, on all points of sailing.

References

(1). The 40 Knot Sailboat, Dr Bernard Smith.
(2). Catalyst Number 5

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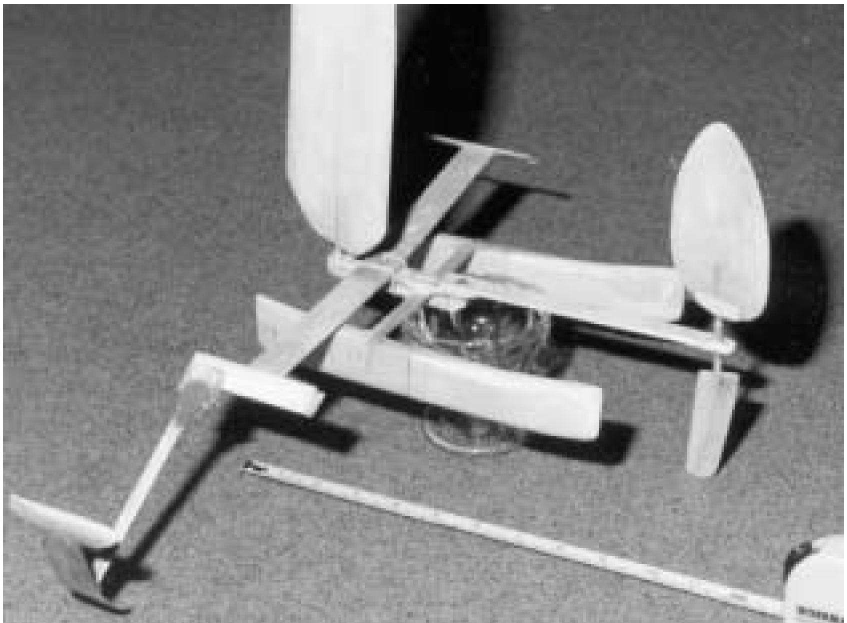

Figure 4. The 10" catamaran was my first successful articulated foil (hapa) stabilised craft.

Figure 5. The 12" skiff was the first HSSC to plane on a reach, and achieve stable foilborne operation.

Figure 6. This 20" version was disappointing. In getting it to work, I fitted a vane steered canard rudder, moved the rig forward and raised it, lengthened the hull to 24" to cure the dragging transom, and doubled the effective span over the foils.

The self-tacking mainsail slat made it easier to tune for maximum coefficient of lift without stalling the rig.

Figure 7. Now 24" long, and with much greater effective beam.. This was further developed in Australia to work really well. Tuning to optimise performance was very tricky, but it all came together on 14 November 1997.

Waves pass between the hull and the lift foil.

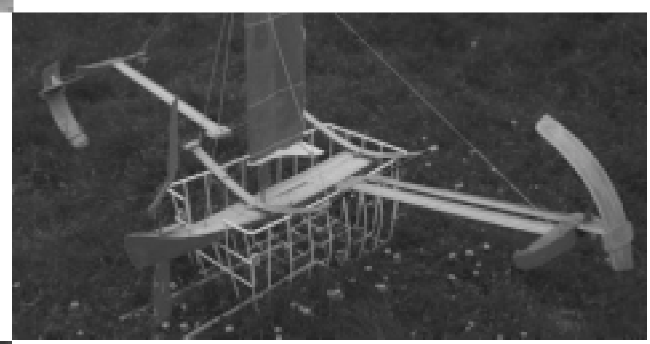

Figure 8. HS24 Skiff, with hapa deployed for starboard tack. These hapa foils are housed in daggerboard style cases, and are interchangeable rather than being handed pairs, so that only one type of foil is needed.

Figure 9. HS48 canard rudder showing servo linkage, arranged so that the rudder angle is unaffected when the rudder knocks up.

Figure 10. HS48 trimaran set up for port tack, rudder folded back, viking prows, swing wing akas, and self tacking wing sail (under-sized).

The Smart Anchor or Terradynamics

Jack Goodman

In any discussion with sailors about anchoring, I have noticed a similarity with discussions about religion. I believe it has to do with faith. When we anchor, we go through the routine of dropping the anchor and backing down, then trusting to faith that we will still be there in the morning. This thought led me to keeping a sandbox in the basement, where I make models of anchors and test them to see what happens.

All of the plow type anchors set easily and proceed to dig themselves in. At some point they all tend to roll out until they get close to the surface, then they reorient themselves, and dig back in. From my observations it appears that they orient themselves initially by gravity. When gravity becomes a smaller percentage of the pulling force, it is no longer strong enough to guide them. In denser sand or mud, this is seldom a problem since the anchors never have to go too deep to generate the necessary holding force.

We live in the Chesapeake Bay, where we really know about mud and have to live with it. I have found several places with wonderfully consistent mud, where I can test my larger, two pound prototypes. I can drag them around, and can produce identical forces day after day. In my testing, the Danforth type is the champion in really deep mud. The problem with Danforth anchors is that they are two sided. They rely on gravity to pull the flukes down to set. If you swing 180 degrees over them, and they flip over, a small stick or oyster shell can keep the flukes from falling to the other side, and keep it from resetting.

My experiments have led me to search for an anchor design with the following attributes.

1. A single sided anchor, that can initially orient itself to begin penetrating the bottom.
2. An anchor that has the ability to remain vertical even under full load.
3. An anchor with enough wing area to be able to penetrate deep mud. A problem because the larger the wing, the more difficult it is to get them to initially orient themselves point down.

For the last six or seven years I have made small models using sheet brass, sheers and a soldering iron. The ones that look promising are taken down to my dock and tested in average density mud with usually average results. One night I dreamed of bending the ears of one of the models downwards, in what seemed to me to be an illogical direction. The next morning I tried it. The anchor flipped right side up and went straight down, and unlike the other anchors, it left almost no wake, just a thin line where the rode had been. In medium the density mud the 2 oz. model repeatedly held at over 20 pounds, and the 2 pound model often pulls from 310 to over my scale maximum of 400 pounds. That extrapolates to 3200 pounds for a 20 lb. anchor. Incidentally, I have found that anchor holding power is generally related to weight not wing area. Wing area only goes up as the square of the size. A 20 pound anchor would only have 8 times the wing area of a 2 pound anchor. However being larger, there is a second multiplier for the extra depth, or density, it can attain.

This model is roughly triangular and looks much like the spade anchor. The point is weighted like the spade, however the rear wing tips of the triangle stick out and are bent downward. Because of its width the anchor does not necessarily rest point down even though it is weighted. The wingtips dig in and flip the anchor right side up much like in the Bruce anchor design. Once righted, the wingtips work much like dihedral in a model airplane. When one wing is lower, it's flap are in greater density mud, creates more lift, and resist going deeper until the other side is even with it,. My patent attorney immediately named it the SMART ANCHOR. Unfortunately, when I made a larger 22 pound model, and tested it in soft mud it did not fair much better than the other plow type anchors.

The wing or foil of an anchor has to generate enough downward force to pull the chain, rope and shank down, as well as counteract the upward force generated by the angle of rode. The only way to accomplish this is to improve the lift to drag ratio. There should have been enough wing area to get the job done, but it refused to go deep enough to get to good dense earth. About six months later it occurred to me that the lift to drag ratio requirements varied across the depth of the anchor. In the case of a point down, shank up working position of a Danforth anchor, the point is six inches deeper in the mud than the than the bar and shank. Although this may not seem like much, in a gradient, it is a big difference. The deepest part of a Danforth anchor has very low frontal area. This implies that the deepest part of the anchor needs to have a higher lift to drag ratio than the rest of the anchor, and that the shank and chain needs to be kept as high as possible. The prototype anchor had a weighted tip to help it orient point down, and weighed 22 pounds. This weight increased the frontal area and drag at the deepest part of the anchor. To my surprise, when I removed the weight and frontal area, the anchor was still able to turn point down by itself and appeared to perform as well as the heavier Danforth. I have no method of pulling and measuring 2000 pounds. I only know that my heavier, 30 pound, plows could be dragged in the soft mud, while the Danforth and my prototype could not.

A quick note about lift to drag: an anchor is a flying device much like an airplane, only its lift is down and its medium is earth. Anytime an anchor is being pulled hard enough to move, it must slide through the earth in order to produce lift. Contrary to what many people believe, a smooth slippery anchor will develop more drag because it is able to fly deeper. If it stops sliding through the earth it stalls, much like an airfoil.

Also as a general rule I have found that increasing the scope from 5 to 1, to 10 to 1, increases holding power by more than 40%.

There is still much to do before even thinking about production. I have found that even small deviations in shape can have disastrous results. And there are still manufacturing considerations to deal with. As this is a spare time, spare money project, don't look for one at the chandlery just yet. I will keep you posted on further developments.

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Jack Goodman is an inventor that lives on the Chesapeake Bay, and often winters in the south with his wife on their 35 foot catamaran.

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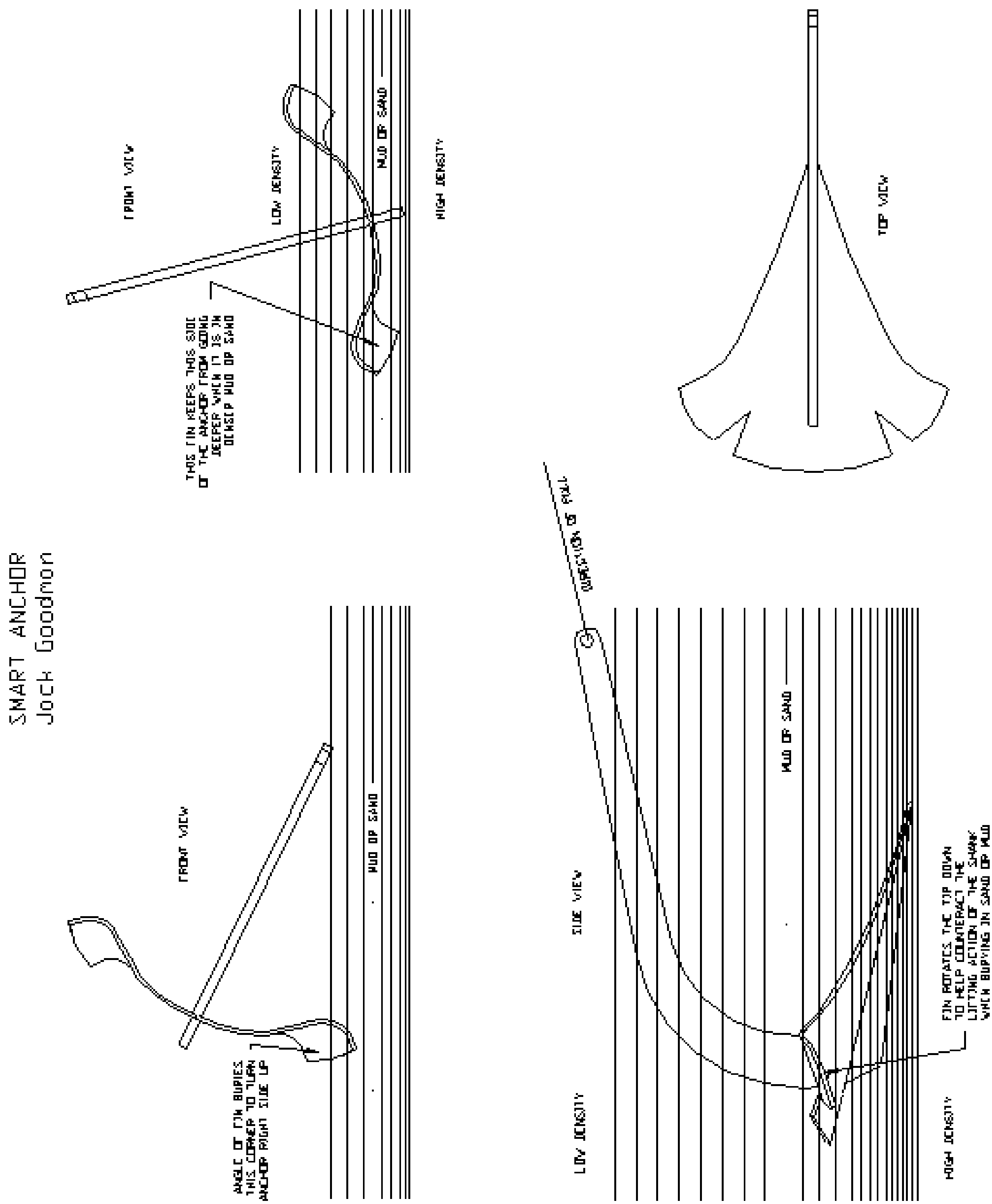

SMART ANCHOR
Jock Goodman
FRONT VIEW
LOW DENSITY
MUD OR SAND
HIGH DENSITY
THIS FIN KEEPS THIS SIDE OF THE ANCHOR FROM GOING DEEPER WHEN IT IS IN DENSER MUD OR SAND
TOP VIEW
DIRECTION OF PULL
FRONT VIEW
MUD OR SAND
ANGLE OF FIN BURIES THIS CORNER TO TURN ANCHOR RIGHT SIDE UP
SIDE VIEW
MUD OR SAND
LOW DENSITY
HIGH DENSITY
FIN ROTATES THE TIP DOWN TO HELP COUNTERACT THE LIFTING ACTION OF THE SHANK WHEN BURYING IN SAND OR MUD

THE MILL-PROP PARADIGM AND THE EXPANSION OF SAILING

Peter A. Sharp

A "paradigm" is an explanatory model. But it can include multiple theoretical and mathematical explanations. It can be a whole way of looking at, and understanding, some aspect of the world. The mill-prop paradigm is, ultimately, a new way of understanding sailing. It is a paradigm shift from the old way to a new way. It is not mathematical, but it is logical and technical. It is a purely theoretical work in basic yacht science. However, more often than not, theoretical insights in the physical sciences eventually lead to new inventions, and sometimes to technological breakthroughs.

I begin by showing that two sailing craft, currently assumed to be quite different craft, are actually variations of the same underlying craft. That realization leads to asking what defines those craft. And that definition leads to the categorization of such craft and to the discovery that there are a great many more such craft. Part of their definition requires defining sailing itself. That definition leads to an enormous expansion of what is meant by "sailing". The definitions are not arbitrary. They are based on observable evidence.

This subject matter all fits together like a complex puzzle, and it is difficult to understand. That is because it involves conceptual "reversals" — of media contexts, device combinations, modes, and frames of reference. Unfortunately, the human mind is not well suited to keeping track of reversals. And there are also different levels of abstraction to keep in mind, plus some new terminology. So please do not expect to understand all of it on the first reading. Even though I began to explore this paradigm two years ago, I am still struggling with it at the level of a novice.

As the reader may know, windmill vehicles can sail directly against the wind. They use a windmill (mill) geared to a driven-wheel (prop). In contrast, Bauer propeller vehicles can sail directly downwind faster than the wind. They use a driving-wheel (mill) geared to an air propeller (prop). (A "mill" is defined here as a device for converting energy into power. A "prop" is defined here as a device for converting power into propulsion.) For 30 years, engineers have assumed that those two vehicles use distinctly different operating principles.

But those two vehicles are actually two sides of the same coin. They are like mirror images of each other. They are symmetrical opposites based on an underlying unity. At a higher level of abstraction, they both function in the same way. Fundamentally, they are variations of the same kind of vehicle, a mill-prop craft. A Bauer vehicle going downwind faster than the wind may be described as, essentially, an upside down windmill vehicle (going directly upwind) with its parts modified to match its media and direction. In fact, each vehicle behaves like the other if the media context is reversed. For example, if the air is still, and the supporting surface is moving, then a Bauer vehicle can sail directly against the moving surface, and a windmill vehicle can sail directly "down surface" faster than the moving surface. (It can outrun the moving surface.)

Most engineers assume that windmill and Bauer vehicles are already well understood. However, that view is incorrect. While indeed elegant, and while complete enough for engineering purposes, the existing mathematical explanations fail completely to recognize or to explain the remarkable similarities between windmill vehicles and Bauer vehicles. Nor do they delineate the far reaching implications of those similarities for sailing in general. The mill-prop paradigm does so. It is a higher order (more abstract) explanation that includes the existing mathematical explanations as subordinate, special, cases.

The mill-prop paradigm explains in detail why windmill and Bauer vehicles are functionally equivalent (their fundamental principles of operation are the same) when described at a higher level of abstraction (where their mills and props are treated as equivalent, and where their mill media, and prop media, are treated as equivalent). It further reveals that those two craft represent merely 2 of the 9 basic device combinations (mill plus prop) of mill-prop craft.

A defining characteristic of mill-prop craft, which differentiates them from "mill-sail" craft (see below), is that they are able to move directly against their mill medium. The other category of craft that would be able to move directly against the mill medium are power alternating sailing (PAS) craft, since PAS craft typically incorporate mills and props.

Finally, the mill-prop paradigm now makes possible the classification of sailing craft into four general categories: conventional sailing craft (the drag or lift of a sail is used to produce thrust directly), mill-sail craft (a rotating device, rotated by a mill, produces thrust like a sail), mill-prop craft (a mill rotates a prop), and PAS craft (a slow or stationary "on" mill advances an "off" mill at high speed, and then they alternate). Since each of these four categories can have a great many craft variations (based on how the craft are supported against gravity), and since most variations (or their functional equivalents) can operate in all 12 media contexts (and their equivalents), there are an enormous number of new types of sailing craft that could be invented. Thus the mill-prop paradigm enormously expands the purview of sailing. For yacht science, that is a major paradigm shift. It is a fundamentally new way of understanding sailing.

Background Information

Windmill craft may convert wind energy into power using a wide variety of windmills. Many windmill boats and a few windmill vehicles (land yachts) have been constructed. Typically, a windmill is geared to a wheel of a land yacht, or to the water propeller of a boat. Efficiency may be maximized by providing means to vary the pitch and the speed ratio of the windmill blades, and the same for the water propeller.

Efficient windmill craft on land or water can go directly upwind at roughly 50% of the true wind speed, although this speed varies with the interaction of many variables, such as the streamlining of the vehicle, the efficiency of the windmill and the transmission, the rolling friction of the wheels and bearings, the hydrodynamic drag of a hull, air density, etc. When windmill land yachts and boats go directly downwind or across the wind, they are only a little faster. Their speed directly downwind is only a little faster because both power and propulsive drag diminish rapidly as the apparent wind (from behind) diminishes.

The reason that a windmill vehicle can go directly upwind is that initially, when just starting to move upwind, the air drag on the windmill is proportional to the square of the wind speed, but the driving power produced by the windmill is proportional to the cube of the wind speed. So, initially, there is more drive than drag. But as the vehicle begins to accelerate upwind, the drag increases faster than the power, thus limiting the vehicle's ground speed to roughly 0.5 times the true wind speed — as determined by the magnitudes of all the variables. The energy in the wind depends upon its speed relative to the ground, and that does not change as the vehicle accelerates. Given low enough gearing, almost any windmill vehicle can move directly upwind. But the maximum speed ratio (craft speed divided by the true wind speed) will depend primarily upon its overall efficiency.

A Bauer land yacht is a special purpose, wind powered vehicle designed to go directly "downwind faster than the wind" — to outrun the wind. It typically needs an extended push to get it started. Andrew B. Bauer, an aircraft engineer, calculated more than 30 years ago that, if constructed so as to be moderately efficient, a land yacht using an air propeller spun by a rolling bicycle wheel (via a bicycle chain) should be able to go directly downwind roughly 50% faster than the wind (a ground speed of 1.5 times the speed of the wind) given the specific magnitudes of all the variables in his calculations.

Bauer built and rode such a land yacht in 1969 in a wind of about 12 mph (5.4 meters/sec.). The sturdy, wood, open-framed (not streamlined) vehicle used a rolling bicycle wheel to transmit power via a bicycle chain, twisted 90 degrees, to a large, efficient propeller with a variable pitch. The propeller was about 15 feet (4.6 meters) in diameter. The vehicle started downwind using the propeller as a crude windmill ("crude" since the twist of the blades was in the wrong direction). At about 0.6 of the wind speed, he changed the blade pitch so that the windmill became an efficient propeller powered by the bicycle wheel. The vehicle was then able to continue to accelerate and to exceed the speed of the wind during a 40 second run. It sustained about 14 mph.

On another run, he briefly achieved about 15 mph (6.7 meters/sec.) in a 10 mph (4.5 meters/sec.) wind, or about 50% faster than the wind, as predicted by his calculations. Bauer used a tuft of yarn mounted on the front of the vehicle to show when the vehicle exceeded the speed of the wind. When Bauer backed up his vehicle (into the wind) for another run, using the propeller as a windmill again, the vehicle moved directly upwind at about 6 mph (2.7 meters/sec.) in a wind of about 12 mph (5.4 meters/sec.) — about 50% of the speed of the true wind.

Bauer published an article in 1969 that described his experiment, and he included a mathematical explanation. In his article, he also mentioned that a boat — with a water turbine rotating an air propeller — could function similarly. (In principle, it could. But in practice, the drag might be too high for it to outrun the wind.)

In 1995, Bauer placed a model Bauer vehicle (with a fixed-pitch, four-bladed air propeller) on a moving conveyor belt about 5 feet (1.5 meters) long, in a windless room. He held the model in place until the propeller was spinning. When released, the model easily moved against the direction of the belt faster than the belt was moving. That behavior was analogous to going "downwind faster than the wind" because it does not matter which medium is actually moving, the air or the supporting surface. Lowering the belt speed caused the model to begin to move "downstream" with the belt. The belt speed could be adjusted so that the model remained at about the midpoint of the belt.

This demonstration took place during December of 1995 in the presence of Dr. Paul B. MacCready at AeroVironment, Inc. in Monrovia, California. Around June of 2001, a repeat of this demonstration was video-taped by Professor Frederick G. Allen of UCLA (personal communication, Andrew B. Bauer, 7/08/01). If the belt had been longer, the model might have been able to reach a speed against the direction of the belt equal to roughly 150% of the speed of the belt. In other words, if sufficiently efficient, the model might have been able to advance against the belt at a speed roughly 50% greater than the speed of the belt.

An Inconsistency In The Current Paradigm

Bauer's outdoor and indoor demonstrations successfully validated his remarkable concept. However, let us reconsider what was going on in that conveyor belt demonstration. We will notice a subtle inconsistency. A new paradigm often arises from the observation of an inconsistency in the existing paradigm.

To begin with, let us define Bauer vehicles and windmill vehicles in the conventional way in order to help us to see the inconsistency. Let us define a windmill vehicle as a vehicle which is able to advance "directly against the medium that propels it". And similarly, let us define a Bauer vehicle as a vehicle which is able to "outrun the medium that propels it". These are common sense definitions based on the current understanding of the vehicles — the current paradigm, the conventional wisdom.

Using these definitions, let us reconsider the model Bauer vehicle on the conveyor belt in a windless room. Its behavior was, as Bauer correctly pointed out, analogous to going "downwind faster than the wind". With respect to the operation of the vehicle, it does not matter which medium is actually moving. To make the analogy, we mentally "reverse" the media context. That is, we imagine the vehicle outdoors on the ground, with the air moving, and the supporting surface stationary.

However, if we look at the actual behavior of the model on the conveyor belt, it went "directly against the medium that propels it" (the conveyor belt). That behavior fits our definition of a windmill vehicle, not a Bauer vehicle.

To further illustrate this inconsistency, let us create an imaginary model windmill vehicle, and place that model on a (very long) imaginary conveyor belt in a windless room. We will face the model in the same direction that the belt is moving. The model would be carried along by the belt. The relative wind thus created would spin the windmill, and the windmill would rotate one or more of the vehicle's wheels.

The result would be that the model would roll along the belt in the same direction that the belt were moving, and roughly 50% faster than the belt. In other words, the windmill vehicle would "outrun the medium that propels it". That behavior of the imaginary windmill vehicle would be perfectly analogous to the behavior of a full scale windmill vehicle outdoors in a real wind, heading directly upwind, because it does not matter to the vehicle which medium is moving, the air or the supporting surface. But the actual behavior of the imaginary windmill vehicle fits our definition of a Bauer vehicle, not a windmill vehicle.

Apparently our common sense definitions of the vehicles make a distinction without a reliable difference. That is the inconsistency in the current paradigm. Windmill vehicles can go directly "up medium against the medium that propels them". But so can Bauer vehicles. Bauer vehicles can "outrun the medium that propels them". But so can windmill vehicles. Both vehicles can satisfy both definitions if they are placed in the appropriate media contexts. Let us explore this observation further in order to clarify it.

Windmill vehicles and Bauer vehicles are actually remarkably similar vehicles. Given appropriate media contexts, both vehicles have the same two behavior modes. That is, both vehicles have a media context in which they can move against the moving medium (mode A), and both vehicles have a media context in which they can outrun the moving medium (mode O). So we now know that a windmill land yacht (or a windmill boat) has two different behavior modes depending upon which medium is moving. And the same is true for a Bauer land yacht (or a Bauer boat).

Whether these vehicles would be able to operate in their A mode A or O mode would depend upon the media context — which of the two relevant media is moving. The device combination alone (mill plus prop) does not define the vehicle's behavior.

Bauer vehicles behave like windmill vehicles, and vice versa, when the media context is reversed. A "context reversal", as described above, is when a media context is changed such that the moving medium becomes the stationary medium, and visa versa. Reversing the media context can cause each vehicle to switch its behavior — from A mode to O mode, or vice versa. Both device combinations have two behavior modes: A and O. However, from the frame of reference of the vehicle, the A mode and the O mode are identical.

Assuming a two-media context, with one medium moving, each craft is able to operate in two modes, depending upon which of its two media is moving. Mode A is when the craft is able to move against the moving medium. In A mode, the craft's mill (energy conversion device which produces power) interacts with the moving medium. Mode O is when the craft is able to outrun the moving medium (or only nearly so, if the craft is inefficient). In O mode, the craft's prop (propulsion device) interacts with the moving medium.

Of course, sailing on conveyor belts is extremely uncommon and not much of an issue, so we might be tempted to ignore it. But sailing on rivers is common. If we put a windmill boat on a rapidly flowing river during windless conditions, it would be able to sail down river faster than the river. That would be the O mode of the windmill boat. It would outrun the moving medium. And similarly if we put a Bauer boat on a river during windless conditions, it might be able to sail directly up river — if the river were flowing fast enough, if the hull drag were low enough, and if the boat were given a push to get it started. That would be the A mode of the Bauer boat. It would move directly against the moving medium.

However, a dirigible equipped with an air propeller and a water-mill would be more efficient than a Bauer boat for going up river under windless conditions — due to the dirigible's much lower "hull" drag. It would work like a Bauer boat. As we will see from the Appendix (page 24 et seq), both the Bauer dirigible and the Bauer boat going up river are both members of Code category "LΛg", which is one of 24 basic context/device/mode combinations. Each Code category contains many different types of craft, depending upon how they are supported against gravity.

A windmill vehicle and a Bauer vehicle would also reverse their behaviors if we reversed the frame of reference from the supporting medium (ground) to the air (or vice versa). Let us call such a change a "frame of reference reversal". If we apply a frame of reference reversal to an outdoor Bauer vehicle, then the frame of reference becomes the air rather than the ground. That is, the air is assumed to be stationary and the ground is assumed to be "moving". From the frame of reference of the air (wind) outdoors, a Bauer vehicle behaves like a windmill vehicle. It goes "up ground against the ground". And a windmill vehicle goes "down ground faster than the ground". So a frame of reference reversal will cause these vehicles to switch their behavior modes (A to O, or O to A). Outdoors, from the frame of reference of the air, a Bauer vehicle functions and behaves, essentially, like an upside down (and appropriately modified) windmill vehicle, and vice versa.

We can now see that our common sense understandings of Bauer vehicles and windmill vehicles are not consistent because how the vehicles behave depends upon combining 1) a specific device combination (mill plus prop) with 2) a specific media context (meaning: a two-media context, with one medium moving relative to the other), and 3) a specific frame of reference.

The Functional Equivalence of Windmill Vehicles and Bauer Vehicles

The frame of reference of the vehicle may be used to demonstrate the "functional equivalence" of windmill vehicles and Bauer vehicles. By "functional equivalence", I mean that even though their device combinations differ, their device combinations function in the same fundamental manner if we use a higher level of abstraction. At a higher level of abstraction, their mills are treated as equivalent and their props are treated as equivalent. Likewise, their "mill media" are treated as equivalent, and their "prop media" are treated as equivalent. The mill medium is the medium that interacts directly with the vehicle's mill. And the prop medium is the medium that interacts directly with the vehicle's prop.

If we use the frame of reference of the vehicle, then the behavior of a vehicle will not change when we reverse its context. That is because the vehicles will not "see" any significant difference. So, from the frame of reference of the vehicle, it will not matter which medium is "actually" moving.

For example, an outdoor Bauer vehicle going downwind faster than the wind would see the air and the supporting surface coming toward it. The air would be approaching slowly, and the supporting surface would be approaching rapidly. Then, if placed on a conveyor belt in a windless room, and if going "up belt faster than the belt", it would see the same thing. So, from the frame of reference of the vehicle, a media context reversal would not make any difference.

If we use the frame of reference of the vehicle, a windmill vehicle going upwind against the wind would see the air and the ground (supporting surface) coming toward it. The supporting surface would be approaching slowly, and the air would be approaching rapidly. And similarly, if placed on a conveyor belt such that it went "down belt faster than the belt", it would see the same thing. So a media context reversal would not make any difference.

From the frame of reference of the vehicle, a windmill vehicle going upwind would see the wind coming toward it faster than the ground. And a Bauer vehicle going downwind faster than the wind would see the ground coming toward it faster than the wind So, from the frame of reference of the vehicle, what a windmill vehicle and Bauer vehicle would see is the opposite. That is, the windmill vehicle would see the air coming toward it faster than the ground, and the Bauer vehicle would see the ground coming toward it faster than the air.

But now let us move to a higher level of abstraction and ask how they see their respective "mill media" and "prop media". When we do, we can see that the medium that interacts with the mill, the mill medium, is the faster medium in both cases.

The mill medium for a Bauer vehicle is always the supporting surface (ground, or belt) in contact with the wheel-mill (driving wheel), even though an outdoor Bauer vehicle extracts its energy, ultimately, from the wind. When a Bauer vehicle is going downwind at the same speed as the wind, there is no wind relative to the vehicle. So the only available source of direct energy for the wheel-mill is the ground (the mill medium), even though the true source of energy is the wind, and the ground only appears to be moving (relative to the vehicle). From the frame of reference of the vehicle, it does not matter which medium is actually moving. All that matters is a relative motion in the correct direction.

For a windmill vehicle, the mill medium is always the air, even in the case of the imaginary model windmill vehicle on a conveyor belt in a windless room. There, the air (the mill medium) is still the source of direct energy for the windmill, even though the true source of energy is the conveyor belt, and the air only appears to be moving (relative to the vehicle). From the frame of reference of the vehicle, it does not matter which medium is actually moving. All that matters is a relative motion in the correct direction.

For a windmill vehicle, the prop medium is the supporting surface (ground, or belt). For a Bauer vehicle, the prop medium is the air.

Let us assume that a windmill vehicle is going directly upwind at 0.5 times the true wind speed. And let us also assume that a Bauer vehicle is going directly downwind at 1.5 times the true wind speed. Then, from the frame of references of the vehicles, let us compare their respective speed ratios relative to their respective mill media and prop media.

When we do, we see that they are identical. The windmill vehicle and the Bauer vehicle both see their mill media coming toward them at 1.5 times the true wind speed, and they both see their prop media coming toward them at 0.5 times the true wind speed. So at this higher level of abstraction, we may say that windmill vehicles and Bauer vehicles are "functionally equivalent". They work in the same fundamental manner even though their device combinations differ. They are functionally equivalent variations of the same fundamental type of craft. In other words, at a higher level of abstraction, their device combinations function in the same fundamental manner even though, in a given media context (for instance: air moving, surface stationary), their mills are tapping opposite media, and the craft are moving in opposite directions. They are functionally equivalent. They operate in the same basic manner. They are functionally symmetrical. They are two sides of the same coin.

If Bauer had originally built a Bauer dirigible (rather than a land yacht) using a water-mill to spin an air propeller, it might have been easier to notice this functional equivalence. A Bauer dirigible could easily outrun the wind, and it would not need a push to get it started. That is because a Bauer dirigible drifting downwind as fast as the wind would start with a zero speed relative to the air, just like a windmill vehicle (going directly upwind) starts with a zero speed relative to the ground.

Conversely, note that a windmill dirigible (using a windmill to spin a water propeller), and heading directly upwind, might need a push to get it started even though it is a windmill craft. Since sailing craft are powered by the relative motion between two material media, whether or not a windmill craft or a Bauer craft would need a push to get it started would depend upon the extent to which the craft experienced a help or a hindrance from the media in contact with the craft. Media drag may initially assist or retard the forward motion of the craft. Usually, one medium, the supporting medium, will exert a stronger drag force on the craft than the other medium (or other media, in cases where the craft is in contact with more than two media).

However, there is still an apparent discrepancy that needs to be explained. Bauer vehicles and windmill vehicles seem to differ significantly because windmill vehicles can go both upwind and downwind, whereas Bauer vehicles can go only downwind. Exploring the reason for this difference will further confirm the functional equivalence of the vehicles.

The Zero Speed, the Transition, and the Switching Point

The two vehicles actually behave in the same fundamental manner. But to see that equivalence we must again use a higher level of abstraction. To help explain this aspect of their functional equivalence, I will introduce two concepts: the “zero speed” and the “transition”.

The zero speed is when the vehicle has a zero speed relative to its prop medium. So, for an outdoor windmill vehicle, the zero speed is when the vehicle has zero ground speed (it is standing still). For an outdoor Bauer vehicle, the zero speed is when it has zero air speed (when it is going downwind exactly as fast as the wind).

For both vehicles, the beginning of the transition is defined as when they are going downwind at half the speed of the true wind, as seen from the usual frame of reference of the ground. The windmill vehicle faces upwind while backing up at roughly 0.5 times the speed of the wind. It decelerates to a stop (its zero speed) and then accelerates upwind until it is going forward into the wind at roughly 0.5 times the speed of the true wind. That is its transition. (In practice, it might need to use an infinitely variable and reversible fluid transmission, or perhaps just a clutch. Recall that the pitch of Bauer’s propeller was reversible and infinitely variable, so it served as a fluid transmission.)

From the frame of reference of the ground, the transition for the Bauer vehicle starts with the vehicle facing downwind, and moving downwind at roughly 0.5 times the true wind speed. It accelerates up to 1.0 times the true wind speed (its zero speed) and then continues to accelerate up to roughly 1.5 times the true wind speed That is its transition.

During their transitions, both vehicles change direction at their zero speed, relative to their prop medium. For a windmill vehicle, that change of direction is obvious since it must come to a stop. In order to visualize the change of direction for a Bauer vehicle relative to its prop medium, imagine yourself moving with the wind, and positioned in the air above the anticipated zero speed point of the Bauer vehicle. In other words, use the air as your frame of reference.

The Bauer vehicle will back up toward you, stop momentarily beneath you (its zero speed), and then reverse direction and move away from you in the same direction from which it came. The same behavior may be seen by observing a model Bauer vehicle on a conveyor belt in a windless room. Start the model near the head of the belt (toward which it is facing). Let the model go before its propeller is spinning quite fast enough to hold its position. You will see the model “backing up” relative to the air. As the model continues to accelerate, it will, at some point, slow to a stop (become stationary) relative to the air (its zero speed), and then it will begin to accelerate forward relative to the air.

Relative to the air, its mill medium, a windmill vehicle accelerates during its entire transition. Similarly, a Bauer vehicle accelerates relative to the ground (or belt), its mill medium, during its entire transition.

The fact that Bauer's original vehicle switched from using its rotor as a windmill to using its rotor as a propeller is merely a characteristic of that specific vehicle, which needed a push (from a windmill) to get it started downwind. In contrast, a Bauer dirigible (using a water-mill and an air propeller), going downwind over water, might not even have a switching point since it would initially move downwind at the speed of the wind by just drifting with the wind. So the switching point, if one is required, is usually determined by the degree to which a medium's "drag" on the craft serves to facilitate or hinder the craft's initial acceleration. For example, if a Bauer vehicle were to use a large spinnaker to get it started downwind, its switching point could be higher than 0.6 times the wind speed.

A similar analysis applies to windmill boats and Bauer boats. However, Bauer boats may never be able to sail downwind faster than the wind because they experience much more retarding drag, from both the water-mill and the hull, than does a Bauer land yacht. On the other hand, a Bauer dirigible over water might be able to outrun the wind more easily than a Bauer land yacht.

Sailing A Bauer Dirigible Downwind Faster Than the Wind Over Water

A Bauer dirigible can be easily simulated at model scale in order to prove that it is possible for a sailing craft to sail downwind faster than the wind over water. This experimental apparatus would be analogous to Bauer's conveyor belt demonstration.

To provide the necessary relative motion, merely rotate the water in a child's wading pool with a paddle. Or, run water continuously from a hose. Mount a mill-prop unit at the end of a horizontal supporting arm just above the water. Pivot the supporting arm on a vertical bearing located at the center of the wading pool. For the mill-prop unit, use a model water-mill (such as a model boat's racing propeller running in reverse) and a model airplane propeller (probably from a rubber band model for maximum pitch) on opposite ends of a common drive shaft. Tilt the mill-prop unit so that only the water-mill is in the moving water. When the propeller is up to speed, release the arm.

If the arm were able to rotate slowly and continuously against the direction of the water, that would be evidence that the Bauer dirigible concept is valid, since it does not matter which medium is moving, the air or the water. And it does not matter if the mill-prop unit is supported against gravity by a dirigible or by a rotating arm. They are equivalent.

Defining Mill-Prop Craft

We now know that windmill vehicles and boats, and Bauer vehicles and boats, are, at a higher level of abstraction, functionally equivalent variations within a larger category that includes them all. So let us call that larger category "mill-prop craft". The definition of a mill-prop craft is: A craft that obtains its motive power from the relative motion between two, adjacent, material media that are external to the craft (such as air and ground, air and water, etc.), or between different parts of the same or similar media (like two liquids moving at different velocities) by means of a mill (such as a windmill, water-mill, driving-wheel, or equivalent device) appropriately coupled to a prop (such as an air propeller, water propeller, driven-wheel, or equivalent device).

The mill medium may be the moving medium or the stationary medium. Each mill-prop craft (device combination) will have two modes of operation (mode A and mode O) depending upon which of the two media is moving. It is important to note that the two media must be material media (have mass). (Craft that use gravity for propulsion are gliding craft, not sailing craft. Gliders are not "sail planes"; the analogy is incorrect. Gliders are "gravity airplanes".)

A characteristic of mill-prop craft that differentiates them from mill-sail craft (see below) is that they are able to move directly against their mill medium. Even though a windmill vehicle moving downwind or across the wind is not moving directly against its mill medium, it nevertheless would be able to do so (once given a starting push in some cases).

Windmill vehicles and Bauer vehicles look different only because they must use mills and props that match their media contexts and their intended modes of operation. They are actually the same basic vehicle equipped with different parts to match their intended tasks. The vehicle in the drawing uses wheels, and a wheel can function as either a mill or a prop without any outward differences in appearance. If windmill vehicles and Bauer vehicles could use a rotor disc that could function as either a windmill or a propeller without any outward differences in appearance, then it would be obvious that windmill vehicles and Bauer vehicles are, in fact, the same vehicle. It is possible to construct such a rotor disc. It is called an SRD (see below).

The first mention of the possibility of a GΛg mill-prop craft — an airplane propelled by using a windmill and an air propeller at significantly different altitudes, so as to take advantage of the velocity differences at different altitudes due to the wind gradient — may have been a 1985 article in Wind Power Digest by Nguyen Dung, 83 Hang. Bo, Hanoi, Vietnam. Dung was then a half-time worker at the College for Workers, Hanoi. His short article included a mathematical explanation of how an airplane might fly directly upwind using wind power. However, he apparently had not read Bauer's article. If he had, he might have also realized that an aircraft could fly downwind faster than the wind (as a gΛG mill-prop craft). Mill-prop airplanes, or dirigibles, may someday be able to sail against, and faster than, the jet streams. They might be used to convert energy in the jet streams into hydrogen.

As we already know, a specific craft may incorporate more than one device combination, as did Bauer's original land yacht. His vehicle started downwind as a GΛs mill-prop craft (specifically, a windmill land yacht), and then converted to an gΛS mill-prop craft (specifically, a Bauer land yacht) by changing the pitch of the rotor blades. Similarly, a Bauer boat could start downwind as a GΛl mill-prop craft (specifically, a windmill boat), and then convert to an gΛL mill-prop craft (specifically, a Bauer boat). When going down wind while operating as a Bauer boat, it might be faster than when operating as a windmill boat, but it probably could not exceed the speed of the wind due to the excessive drag.

A mill-prop craft may be supported by either of its two primary media, or by a third medium. In rare cases, it might also move through a fourth medium. An example would be a land yacht that used an adjacent canal as its mill medium, and a parallel canal as its prop medium, while being supported by the ground between the canals, and while moving through the air.

Mill-Sail Craft

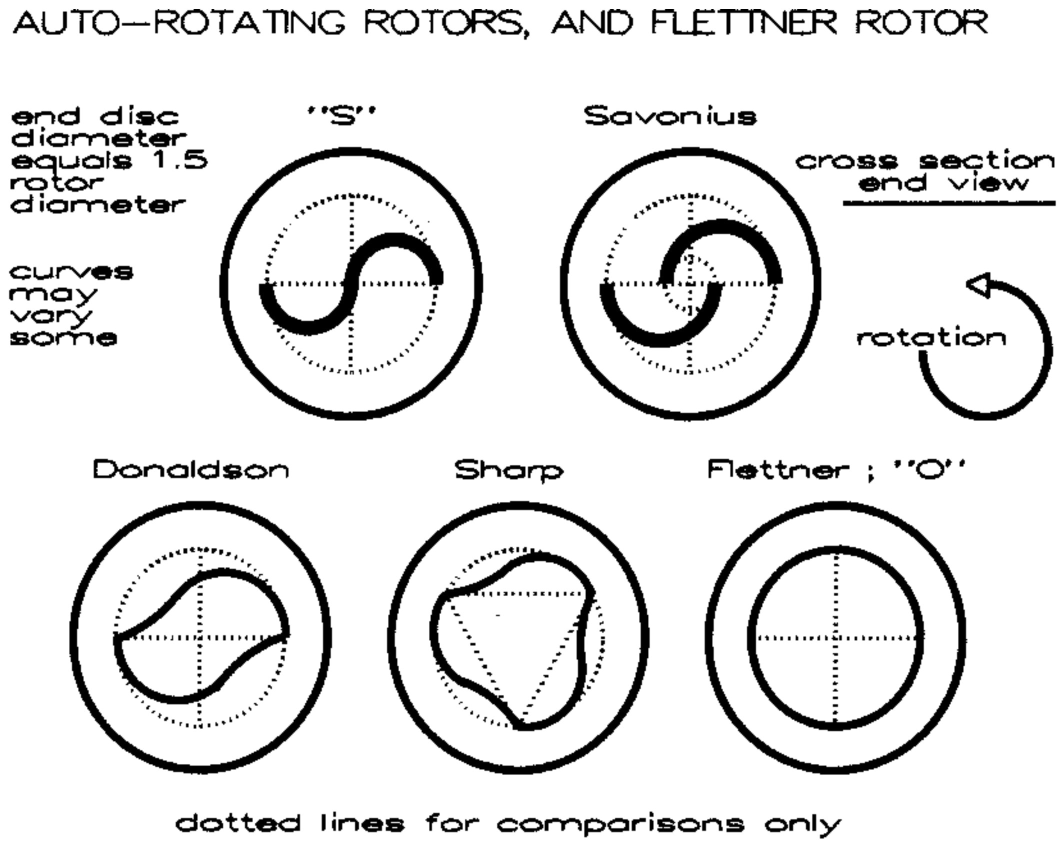
It is possible to construct craft that are similar to mill-prop craft but which do not function in the same way. For example, consider a boat that uses a windmill to spin an air propeller, with both devices mounted on deck. The craft could be sailed rather like a conventional sailboat since that device combination would function like a sail. At first glance, that boat might appear to be a GΛg mill-prop craft. But the craft would not be able to advance directly against its mill medium (the wind acting on the windmill), so it would not conform to the definition of a mill-prop craft. The mere use of a mill and a prop in a device combination is not sufficient, in itself, to define a craft as a mill-prop craft.

Sailing craft that make use of mills and driven devices to create the equivalent of a sail may be classified as "mill-sail" craft. (As a consequence of the mill-prop paradigm, which combines windmill craft and Bauer craft into a single category, sailing craft may be organized into 4 major divisions: conventional-sail craft, mill-sail craft, mill-prop craft, and PAS craft.) Some mill-sail craft may have useful applications. An example is a conventional autogiro sail. Its mill and prop are inherent in the same rotor.

Another example would be a land yacht with a wheel-mill used to spin a Flettner rotor. (A Flettner rotor is a vertical cylinder, with discs at the top and bottom, that is spun by a motor in order to produce lift like a sail by means of the Magnus effect — which causes spinning tennis balls and baseballs to curve in flight.) Note that this mill-sail land yacht would need a push to get it started, as does a Bauer land yacht. Alternatively, the Flettner rotor could be spun manually to get the vehicle started, and then the wheel-mill could be engaged to spin the Flettner rotor faster so as to increase its lift and driving force.

Or, instead of a Flettner rotor, the land yacht could use a vertical, auto-rotating, cylinder-like, Sharp rotor that would start the vehicle moving, and then the Sharp rotor would be connected to a wheel-mill in order to spin the Sharp rotor faster so as to further increase its lift and its driving force. (A Sharp rotor, my invention, has three sides, with each side shaped like an asymmetrical "S". See drawing. Its coefficient of lift rises more quickly than that of a Flettner rotor, as the rpm increases, but it requires a little more power than a Flettner rotor to spin it when driven using an external power source.)

When used as sails, auto-rotating, cylinder-like, rotors may be classified as mill-sail devices because both the mill and the sail are inherent in the rotor. Other auto-rotating rotors include "S" rotors, Savonius rotors (split "S"), and Donaldson rotors (2 asymmetrical "S" surfaces), and their variations. These other auto-rotating rotors require much more external power than a Sharp rotor in order to spin them at an increased rpm, so they are not practical for those applications. Sharp rotors are unique in that they can be both auto-rotating and externally powered in the same application. My experiments with free-flight paper models indicate that "S" rotors and Savonius rotors have lift to drag ratios of roughly 1 to 1, and Donaldson rotors and Sharp rotors have lift to drag ratios of roughly 2 to 1 (they slowly fly twice as far as they descend). Sharp rotors fly faster than Donaldson rotors, thus indicating that Sharp rotors have both lower lift, and lower drag, than Donaldson rotors.



During normal operation, a Flettner rotor on a land yacht would push the wheel-mill, and the wheel-mill would spin the Flettner rotor, so as to produce the driving-force to spin the wheel-mill, and so on. This is similar to how a propeller on a Bauer land yacht pushes the wheel-mill, and the wheel-mill spins the propeller, so as to produce the driving-force to spin the wheel-mill, and so on. Both vehicles function using that odd sort of "mechanical circularity" — a sort of "push me, pull you" relationship. That mechanical circularity seems to be what makes Bauer vehicles particularly difficult for most people to understand. But that mechanical circularity may be a little easier to understand if it is considered in the context of a Flettner rotor land yacht.

Sailing In All Directions

There is one last difference between windmill and Bauer vehicles that needs to be explored. Why is it that a windmill land yacht can sail across the wind, but a Bauer land yacht can not?

A Bauer vehicle's primary limitation is that it lacks a built-in lateral resistance device (LRD), whereas a windmill land yacht has one — its wheels. A secondary limitation is that a Bauer land yacht is supported by its mill medium, rather than by its prop medium. In order to clarify this answer, let us consider a Bauer craft that could sail in all directions.

Consider a Bauer dirigible (Code LΛg) above a river during windless conditions. It would lower its water-mill into the river, and then use its air-propeller to move in any direction relative to the stationary air, and therefor in any direction relative to the ground as well. It would be able to move directly up river at roughly half the speed of the river, and it would not need a push to get started. It would be able to move down river somewhat faster, but not as fast as the river. And it would be able to move across the river at somewhat more than half the speed of the river.

The dirigible's very large side area would serve as a built-in "air LRD". That is, its LRD would interact with its prop medium, the air. The dirigible would also be supported by its prop medium, the air. Most important to note is that the dirigible would be omnidirectional with respect to its prop medium, the air.

The same observations would apply to a windmill land yacht. It would be supported by its prop medium, the ground. Its built-in LRD, its wheels, would interact with its prop medium, the ground. And it would be omnidirectional with respect to its prop medium, the ground.

A Bauer land yacht outdoors does not have a built-in LRD to interact with its prop medium, the air. And it is supported by its mill medium, the ground, not by its prop medium, the air. So it cannot be omnidirectional. Even if it could be omnidirectional, it could be omnidirectional only with respect to its prop medium, the wind. That would not be of much use.

Let us also consider a windmill craft that would not be omnidirectional. A windmill dirigible over a lake could use its windmill to spin its water-propeller in the lake. The dirigible would be able to go directly upwind. But if it tried to move rapidly across the wind, it would be swept downwind by the wind. It would not be omnidirectional because it lacks a built-in LRD to interact with its prop medium, the lake, and because it is supported by its mill medium, the wind, rather than by its prop medium.

A model Bauer vehicle on a conveyor belt in a windless room would have the same problem. It lacks an air LRD, and it is supported by its mill medium. So if it tried to move rapidly sideways across the belt, it would be swept down belt. Similarly, if an outdoor Bauer vehicle tried to move sideways rapidly while going downwind faster than the wind, it would quickly slow down.

In summary: 1) Some mill-prop craft have a built-in LRD, and some do not. 2) The omnidirectionality of a mill-prop craft is limited to its prop medium. 3) Omnidirectionality requires an efficient LRD that interacts with the prop medium. 4) Omnidirectionality is much easier to achieve if a mill-prop craft is supported by its prop medium, rather than by its mill medium.

Consequently, when we analogize by noting that a Bauer vehicle is basically an upside down windmill vehicle that goes "up ground" instead of up wind, we must remember that the analogy applies only to going directly upwind and downwind, not to moving across the wind, since a windmill vehicle has a built-in LRD, but a Bauer vehicle does not.

The Expansion of Sailing

The mill-prop paradigm does not compete with the conventional engineering analyses of windmill craft and Bauer craft. Rather, it completes them, since it reveals the functional equivalence of those craft at a higher level of abstraction, and since it places those craft within their larger theoretical context (mill-prop craft).

However, it might be possible to develop a single, generalized equation, or algorithm, to calculate craft performance within all of the Code categories, since we now know that they are all functionally equivalent. Such an equation or algorithm might be more parsimonious than separate equations for each of the many possible types of craft within each of the 24 Code categories.

Traditionalists may object to expanding the concept of sailing to include all twelve media contexts, instead of limiting sailing to the traditional two (wind and water, plus wind and a solid-surface [ground or ice]). But there is no scientific justification for restricting the concept of sailing to the two traditional media contexts.

In fact, attempts to define traditional sailing as fundamentally different from, or more "real" than, sailing in other media contexts will result in contradictions. For example, a Dung aircraft would use a windmill and a propeller to sail directly against the wind. That is obviously sailing, even though the media context (moving-gas/stationary-gas) is non traditional. According to the traditional definition of sailing, which couples wind with only water, ground or ice, but not with slower air, a Dung aircraft is not sailing when it is sailing. That is obviously contradictory and false.

Another example is a boat sailing across a river under windless conditions by using its keel as a sail, and its sail as an air LRD. That is a new media context (stationary-gas/moving-liquid). The process is equivalent to conventional sailing, but with the device combination, and the media context, both reversed. In other words, it is the same fundamental process, but upside down. A water sail is obviously a sail, and an air LRD is obviously an LRD. From the frame of reference of the sailboat, the relative motion between the two media is exactly the same as during traditional sailing. For sailing, it is irrelevant which medium is actually moving. It is only the relative motion that matters. Yet the traditional definition of sailing asserts that in one case the sailing process is "real" sailing, but then not "real" sailing when using the exact same process. That is obviously false.

Therefore, it is important to understand that most of sailing's media contexts were previously not recognized as such. "Sailing" was assumed to require "wind". But clearly, neither wind, nor air, are necessary for sailing. It is the relative motion between two material media, external to the craft, that is the essence of sailing. Traditional sailing includes those two media contexts that were discovered first — simply because they were ubiquitous, obvious, and practical. The mill-prop paradigm adds, and justifies, the other ten media contexts.

Fundamentally, there is no difference between traditional sailing and sailing in the other media contexts. The fundamental processes are the same. The goal of science is to find explanatory models with the broadest possible scope so as to reveal unexpected connections. The mill-prop paradigm opens the door to a great many insights, inventions, and research models. For example, in a future article I will explore ways to combine water-mills with wingsails so as to increase the reaching speeds of sailboats. Such craft may be, in theory at least, faster than is possible for conventional sailing craft.

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Acknowledgments I am grateful to Andrew B. Bauer and Dr. Paul B. MacCready for their criticisms of an early draft of this article. It was confusing and incomplete. Dr. MacCready wisely recommended that I not publish, so I worked on it for another year. I also thank my partner, Anne Bolla, for many helpful discussions.

[This article is just a part of Peter Sharp's very much longer submission for the 2003 John Hogg Prize. In that he explored in mre detail his ideas and their consequences for yacht science. Unoftunately the submission as a whole is too long for publication in Catalyst. However, copies of the full submission can be obtained on request to the author, or to the AYRS Office, email:ayrs@fishwick.demon.co.uk. -- Ed.]

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Sharp, Peter A.: "Power Alternating Sailing (PAS) — A Proposal for a New Way to Sail Directly Upwind and Downwind Faster than the Wind", Catalyst, Vol. 1, No. 3, Jan. 2001, pp. 26-37. Describes 4 Types of PAS craft. Includes drawings of analog vehicles used to help explain windmill vehicles and Bauer vehicles. Unfortunately, the words "Faster than the Wind" were accidentally omitted from the published title, thus trivializing the subject matter of the article. Please use the correct title when citing the article.

CORRECTION: The PAS trimaran that uses two triangular windmills is incorrect. It is not a PAS boat, only a windmill boat. To function as a PAS boat, each wingsail would need to be equipped with its own LRD, such as a daggerboard. Then preferably, each daggerboard would be pulled out of the water during the recovery part of its cycle when its wingsail was advancing toward the bow of the boat.

Sharp, Peter A.: "The Bauer Vehicle — Michael Collis' objections", Catalyst, Aug. 2001, N0. 5, pg. 7. My response to his objections, plus further comments on the analog vehicle drawings presented in "PAS". Also included are discussions of imaginary "thermal" and "gravity" helicopters, which may now be categorized as gΛS and SΛg mill-prop craft, respectively.

Sutton, Richard Manliffe, Ed., Demonstration Experiments in Physics, McGraw-Hill Book Company, Inc., New York and London, 1938. See page 23 for a typical description of the classic spool and thread demonstration.

Appendix — The Classification of Mill-Prop Craft

We may begin by defining "sailing" as: craft propulsion by means of a driving-force produced by deriving energy from the relative motion between two material media that are external to the craft. The 3 basic material media of interest are gases, liquids, and solid surfaces, or equivalent media. For example, the ground, a conveyor belt, and ice are all equivalent solid surfaces. Even a rope can be an equivalent solid surface if it interacts with a mill or prop, such as a cable drum or pulley wheel. The source of a moving medium's motion may be natural, like the wind, or it may be human-induced, like a breeze from a fan, or a moving conveyor belt in a windless room.

The 3 basic media may be combined into 6 combinations of 2 media each. The 6 combinations of basic sailing media are therefor: gas/liquid, gas/solid-surface, liquid/solid-surface, gas/gas, liquid/liquid, and solid-surface/solid-surface.

In each of the 6 media combinations, either of the two media may be assumed to be moving, while the other is assumed to be stationary. So there are a total of 12 media contexts to consider.

For each of the 12 media contexts, where one medium is moving and the other is stationary, there will be a mill-prop device combination that can move against the moving medium (mode A), and a device combination that can outrun the moving medium (mode O). So there are 24 context/device/mode combinations to consider.

However, note that if we multiply the 9 basic device combination times the 2 modes, the product is only 18, which is less than the 24 context/device/mode combinations. The reason for that difference is that some device combinations have one A mode and one O mode, but others have two A modes and two O modes. See Table I. Also, the former are displayed in the first three divisions of Table II, and the latter are displayed in the last three divisions of the Table II. For an example of the latter, see the drawing of the submarines in oil and water. There, the same device combination has two A modes and two O modes. The Code categories serve to avoid confusion.

First, let us list the 9 basic device combinations of mills and props. Each of these 9 basic device combinations has either 2 modes (A and O) or 4 modes (two A, and two O).

Table I The 9 Basic Device Combinations Used By Mill-Prop Craft

Basic Device Combinations	# of Modes	Familiar Craft
1) windmill/air-propeller	4	———————
2) windmill/water-propeller	2	windmill boat, windmill dirigible
3) windmill/driven-wheel	2	windmill land yacht
4) water-mill/air-propeller	2	Bauer boat, Bauer dirigible
5) water-mill/water-propeller	4	———————
6) water-mill/driven-wheel	2	vehicle on path beside river — goes up river
7) wheel-mill/air-propeller	2	Bauer land yacht
8) wheel-mill/water-propeller	2	—————
9) wheel-mill/driven-wheel	4	Schmidt vehicle; Sharp analog vehicles

More properly, a windmill, a water-mill, and a wheel-mill should be listed using the more general and inclusive terms "gas-mill", "liquid-mill", and "solid-surface-mill", respectively. But the more familiar terms are used for clarity. The terms "wheel-mill" and "driven-wheel" are both meant to include their equivalent devices, such as a pulley wheels, rope drums, or gears. An equivalent "water-mill" could be oars or paddles functioning passively. So it is to be understood that equivalent devices could be substituted for the devices as listed. As mentioned above, it is important to note that each device combination could be embodied in different kinds of craft, depending upon how the craft were supported against gravity. For example, a water-mill/air-propeller device combination could be embodied in a boat, dirigible, hydrofoil craft, surface effect aircraft, etc. Some would be more practical than others.

The 24 context/device/mode combinations are shown in Table II along with their identifying Codes. Since each Code category may include various craft that differ with respect to how they support themselves against gravity, the Code only makes clear that the various craft in that Code category are using a particular device combination, and that they are using it to operate in a particular mode, within a particular media context (and from a particular frame of reference — that of the stationary medium).

Table II The 24 Mill-Prop Context / Device / Mode Combinations and Their Identifying Codes

Basic Media Context	Basic Device Combination	Behavior Mode	Code
Gas and Liquid			
gas moving, liquid stationary	(2) windmill / water-propeller	A, against gas	LΛg
gas moving, liquid stationary	(4) water-mill / air-propeller	O, outruns gas	gΛL
liquid moving, gas stationary	(4) wheel-mill / air-propeller	A, against liquid	GΛl
liquid moving, gas stationary	(2) windmill / water-propeller	O, outruns liquid	lΛG
Gas and Solid-surface			
gas moving, surface stationary	(7) wheel-mill / air-propeller	A, against gas	SΛg
gas moving, surface stationary	(3) windmill / driven-wheel	O, outruns gas	gΛS
surface moving, gas stationary	(3) windmill / driven-wheel	A, against surface	GΛs
surface moving, gas stationary	(7) wheel-mill / air-propeller	O, outruns surface	sΛG
Liquid and Solid-surface			
liquid moving, surface stationary	(8) wheel-mill / water-propeller	A, against liquid	SΛl
liquid moving, surface stationary	(6) water-mill / driven-wheel	O, outruns liquid	lΛS
surface moving, liquid stationary	(6) water-mill / driven-wheel	A, against surface	LΛs
surface moving, liquid stationary	(8) wheel-mill / water-propeller	O, outruns surface	sΛL
Gas (a) and Gas (b)			
(a) moving, (b) stationary	(1) windmill / air-propeller	A, against (a)	G(a)Λg(b)
(a) moving, (b) stationary	(1) windmill / air-propeller	O, outruns (a)	g(a)ΛG(b)
(b) moving, (a) stationary	(1) windmill / air-propeller	A, against (b)	G(b)Λg(a)
(b) moving, (a) stationary	(1) windmill / air-propeller	O, outruns (b)	g(b)ΛG(a)
Liquid (a) and Liquid (b)			
(a) moving, (b) stationary	(5) water-mill / water-propeller	A, against (a)	L(a)Λl\(b)
(a) moving, (b) stationary	(5) water-mill / water-propeller	O, outruns (a)	l(a)ΛL(b)
(b) moving, (a) stationary	(5) water-mill / water-propeller	A, against (b)	L(b)Λl(a)
(b) moving, (a) stationary	(5) water-mill / water-propeller	O, outruns (b)	l(b)ΛL(a)
Solid-surface (a) and Solid-surface (b)			
(a) moving, (b) stationary	(9) wheel-mill / driven-wheel	A, against (a)	S(a)Λs(b)
(a) moving, (b) stationary	(9) wheel-mill / driven-wheel	O, outruns (a)	s(a)ΛS(b)
(b) moving, (a) stationary	(9) wheel-mill / driven-wheel	A, against (b)	S(b)Λs(a)
(b) moving, (a) stationary	(9) wheel-mill / driven-wheel	O, outruns (b)	s(b)ΛS(a)

Key:

"A" means the device combination is intended to enable the craft to move against the moving medium, although in some cases the craft would need a push to get it started. "O" means the device combination is intended to enable the craft to outrun the moving medium, although in some cases the craft would need a push to get it started. "(a)" and "(b)" represent two different velocities within the same medium, or similar media (like two liquids). "g" or "G" = gas; "l" or "L" = liquid; "s" or "S" = solid-surface; or their equivalents. (For example, an equivalent of a solid-surface would be a pulley rope, a rope wound on a drum, or a gear rack).

Interpreting the Code:

The Greek letter lambda ("Λ") indicates a mill-prop Code. When used in a mill-prop Code, the "Λ" is not pronounced. It indicates that the letters or words in the Code should be pronounced all as one word, with the accent on the capitalized symbol or word.

The Code letter on the left represents the moving medium. The Code letter on the right represents the stationary medium. For example, "gΛs" means that the gas is moving and the solid-surface is stationary. The moving medium comes first.

A capitalized letter represents the mill medium. A small case letter represents the prop medium. For example, GΛs means the moving gas is the mill medium, and the stationary solid-surface is the prop medium. So we know that a GΛs mill-prop craft is a windmill land yacht, or an equivalent craft.

Furthermore, if the first letter is capitalized (for example, GΛs) we know that the craft is operating in A mode; that is, it is designed to be able to move against the moving medium. (Whether or not it would actually be able to do so would depend upon the efficiency of the craft and the extent to which media "drag" assisted or hindered the craft.)

And conversely, if the second letter is capitalized, then we know that the craft is operating in O mode; that is, it is designed to be able to outrun the moving medium. So a Bauer land yacht outdoors in the wind is Code gΛS. (On a conveyor belt indoors, it is Code SΛg.)

Again, a craft may use devices that are equivalent to the three basic kinds of mill and the three basic kinds of prop. For example, a wheel-mill could instead be a pulley wheel, or a drum wound with rope, or a pinion gear riding on a gear rack.

Table III Examples of Mill-Prop Craft Within Each of the 24 Code Categories

GΛl Windmill boat going upwind on ocean.

gΛL Windmill boat outrunning river, no wind.

gΛL Bauer boat in wind.

LΛg Bauer boat going up river, no wind.

GΛs Windmill land yacht in wind.

sΛG Model windmill land yacht outrunning indoor conveyor belt.

SΛg Bauer vehicle moving against conveyor belt in windless room. Also, a model airplane propelled by pulling a fishing line aft to spin a drum inside of the airplane, with the drum appropriately geared to an air propeller. To minimize the drag of the line, the drum would need to spin at a much higher rpm than the propeller. Also, a model helicopter could be made to hover using a very light belt around a pulley wheel in the helicopter, with the belt motor at ground level. The belt would need to have a very high surface speed in order to minimize the downward drag of the belt. So the design goal would be to spin the helicopter's pulley wheel at maximum rpm, but with minimum torque.

gΛS Bauer vehicle outdoors.

LΛs Canal boat uses its water-mill to spin a pinion (spur) gear that rides in a continuous gear rack next to the canal. The canal boat goes up the canal against the flow of the canal.

sΛL A rope is wound around a drum on a boat, and the drum is appropriately geared to a water-mill. Pulling the rope forward pulls in the boat forward faster than the rope, as the water-mill spins the drum, and the drum winds in the rope.

SΛl Boat propelled across a river by a crew on the near shore. The crew or a motor pulls the rope to unwind the rope from the drum on the boat, thus spinning a water propeller geared to the drum. A low cost torpedo could also be propelled in this manner using a fishing line and a pedaled reel. A "fishing pole" could be used to steer the torpedo mechanically via the line by moving the pole from side to side, or up and down, to activate the steering vanes on the torpedo.

lΛS Land yacht with wheel-mill beside canal. Wheel-mill spins water propeller in canal. Land yacht outruns flow of canal.

G(a)Λg(b) Parallel tunnels with a horizontal connecting slit running their length. Air flows in tunnel (a), but not in tunnel (b). Wheeled vehicle with air propeller in tunnel (b) uses windmill in tunnel (a) to move against the air flow in tunnel (a).

g(a)ΛG(b) Wheeled vehicle with propeller in tunnel (a) uses windmill in tunnel (b) to outrun air flow in tunnel (a).

G(b)Λg(a) As above, but air flows in tunnel (b), not in tunnel (a). Wheeled vehicle with air propeller in tunnel (a) uses windmill in tunnel (b) to move against the air flow in tunnel (b). g(b)ΛG(a) Wheeled vehicle with propeller in tunnel (b) uses windmill in tunnel (a) to outrun air flow in tunnel (b).

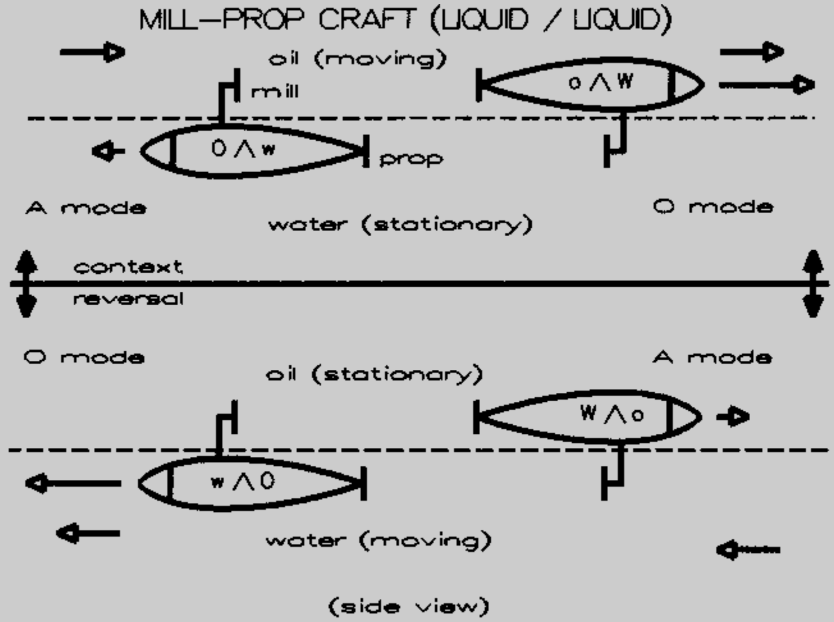
L(o)Λl(w) ; l(o)ΛL(w) ; L(w)Λl(o) ; l(w)ΛL(o) See the drawing of the same submarine operating in 4 modes, depending upon which liquid is moving, and which medium is the mill-medium. Since we know that the media context is "liquid / liquid", we can further simplify the Code to eliminate the references to "liquids", and just use the specific names of the liquids we are concerned with: oil and water. So now the same Codes may be written simply as OΛw ; oΛW ; WΛo ; wΛO. They still indicate which medium is moving, which medium is stationary, and which medium the mill interacts with, and the craft's mode.

S(THREAD)Λs(ground), or simply **THREADΛground** Use a spool of thread appropriately geared to the wheels of toy car on the ground. Pull the thread rearward (aft) to make car go forward.

s(thread)ΛS(GROUND), or simply **threadΛGROUND** Use a spool of thread lying horizontal on the ground. Pull on a length of thread extending from the bottom of the spool. The spool will wind in the thread and catch up to your hand. This is the first part of a classic physics demonstration. The end discs of the spool in contact with the ground create more torque than the spool cylinder in contact with the thread, so the end discs force the spool to wind in the thread, and the spool as a whole "outruns" the thread. It goes "down thread faster than the thread". The thread is analogous to the wind. The spool cylinder is analogous to Bauer's air propeller (prop). And the end discs are analogous to Bauer's wheel-mill. (The other part of the classic experiment: Raise the angle of the thread to near vertical until the imaginary extension of the thread contacts the ground on the near side [near your hand] of the spool's contact point with the ground. That will reverse the direction of travel of the spool when the thread is pulled. The spool will then move away from your hand due to the reversal of torque.)

S(BELT)Λs(thread), or simply **BELTΛthread** Place a spool of thread on a moving conveyor belt. At the head of the belt, hold stationary the end of a length of thread from the bottom of the spool. The spool will go "up belt faster than the belt", and it will approach your hand.

s(belt)ΛS(THREAD), or simply **beltΛTHREAD** Use a spool of thread appropriately geared to the wheels of a toy car. Place the toy car on a moving conveyor belt, facing down belt. Hold the end of the string stationary, and parallel with the belt. The unwinding string will spin the spool, thus spinning the wheels, and thus causing the toy car to outrun the conveyor belt.



In order to give some idea as to the wide range of possible mill-prop sailing craft and how they might function, Table III provides one or more examples of mill-prop craft for each of the 24 Code categories. Each Code category contains potentially many types of craft, depending upon how they are supported against gravity, and depending upon what equivalent devices are substituted for the basic device combination as listed.

As shown above, in Code categories where the two media are both gasses, both liquids, or both solid surfaces, additional symbols or words may be used for clarity as needed. For example, consider a Code category where the two media are oil and water, with the oil floating on the water. If the oil were the moving medium, and if the craft were designed to sail against the direction of the oil, then the craft's Code would be L(OIL)Λl(water). That Code designation could be further simplified to OILΛwater, or just OΛw, as long as it remains clear what the symbols refer to.

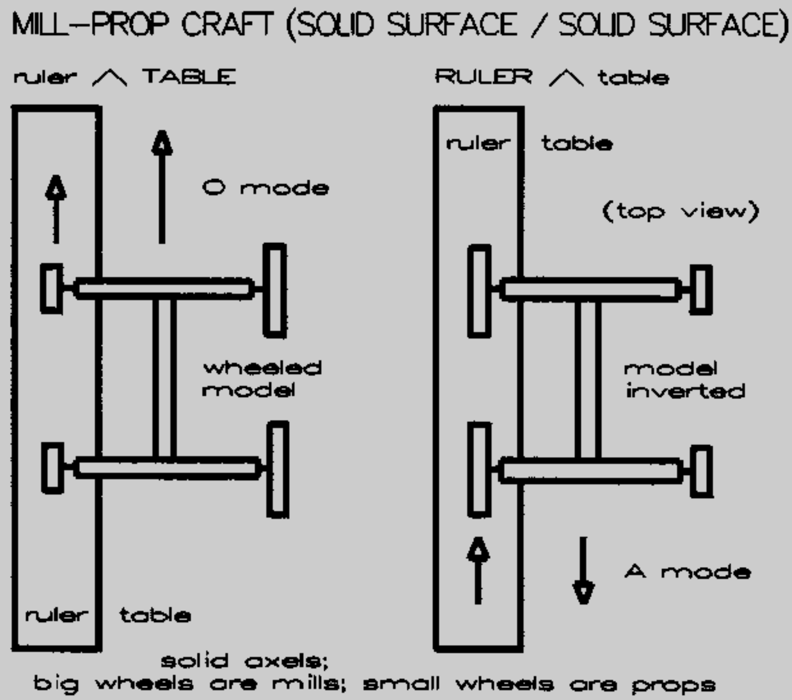
That craft would most likely be a submarine, but we would also need to know if the submarine were floating in (supported by) the oil, in the water, or in both (at the boundary). That information would be stated separately. If the craft were a mill-prop craft Code l(oil)ΛL(WATER), we would know that the oil was the moving medium, and that the craft was designed to outrun the oil by placing its mill in the water. To be most efficient, the craft would be supported within the oil, rather than within the water, so as to take full advantage of the movement (the assisting "drag") of the oil, and to avoid the excessive retarding drag the craft would encounter if supported within the water.

Obviously, there are a great many possible mill-prop craft that have not yet been constructed, nor conceived, since each of the 24 Code categories may contain various craft that differ with respect to how they are supported against gravity, and that differ also with respect to how they construct their specific devices (for example, using a tread instead of a wheel, a pulley wheel instead of a wheel, etc.).

The spool of thread mentioned above — s(thread)ΛS(GROUND) — has been used in physics laboratory demonstrations for perhaps a hundred years or longer. But of course no one realized that it was a model mill-prop sailing craft. It was probably the first.

Another model mill-prop sailing craft that has been unidentified as such for about 20 years is Theo Schmidt's model vehicle (mill-prop Code sΛS) that was sandwiched between two parallel planes, and propelled by the relative motion between those planes. It went "down plane" faster than the moving plane at a maximum speed ratio of about 4 times the speed of the moving plane (because it did not lose energy to fluid turbulence like most mill-prop craft). (See Bibliography.)

Schmidt presented his vehicle as analogous to a Bauer vehicle that could go downwind faster than the wind. But now we know that Schmidt's vehicle was a true model mill-prop sailing craft — just as Bauer's model vehicle on the conveyor belt was more than just an analogy; it was a true mill-prop sailing craft. Schmidt's model was, I believe, the invention of the second Code sΛS model mill-prop sailing craft, but the first to be propelled by the relative motion between two planes.



Schmidt invented the “Schmidt technique” for sailing down plane faster than a moving plane. The Bauer technique and the Schmidt technique are the same fundamental mill-prop technique. But they each use the device combination that is most appropriate for their specific media combinations. While both used a wheel-mill, Bauer’s prop was an air-propeller, and Schmidt’s prop was a driven-wheel. Bauer used basic device combination number 7, while Schmidt used basic device combination number 9.

The spool of thread — s(thread)ΛS(GROUND) — is the equivalent of basic device combination number 9. The thread functions as a solid surface. The end discs of the spool serve as the wheel-mill. The drum of the spool serves as the driven-wheel. The end discs are the wheel-mill because they produce higher torque than the drum, and force the drum to rotate, thus winding in the thread, and pulling the spool “down thread faster than the thread”.

My explanatory wheeled vehicles shown in the drawing in “Power Alternating Sailing (PAS)” are examples of Codes SΛs and sΛS mill-prop craft. (See that drawing here; it is modified to show the vehicles as true mill-prop craft rather than as merely analog vehicles.) The drawing was originally used to help explain how windmill vehicles and Bauer vehicles function. Only later did I realize that they were true sailing craft. The vehicles use side-by-side solid-surfaces rather than Schmidt’s “sandwiching” solid-surfaces. But they are of the same basic mill-prop types as Schmidt’s vehicle.

In the drawing, the ruler is the moving medium, so it comes first in the Code. Since we already know that this is a solid-surface/solid-surface media context, we need not mention that in the Code, since it would be redundant. So the two vehicles are designated as “rulerΛTABLE”, and “RulerΛtable”. We therefor know that “rulerΛTABLE” means that the ruler is moving, and the vehicle’s mill interacts with the stationary table. Since the second word is capitalized, we know that the vehicle is operating in O mode; it is outrunning the moving medium. And similarly, we know that “RULERΛtable” means that the ruler is moving because it is listed first, that the vehicle’s mill (large wheels) interacts with the ruler, and that the vehicle is moving against the moving medium (because the moving medium is capitalized) in mode A. On the other hand, if the ruler were held stationary and the table were pushed, that would be a media context reversal. Both vehicles would then switch modes. Their Codes would then be “TABLEΛruler”, and “tableΛRULER”.

Note that the two vehicles in the drawing are actually just the same vehicle that has been inverted (top to bottom, or front to back). That vehicle therefor demonstrates that for a given media context, the A mode and the O mode are merely inverted (reversed) versions of each other. So if either the vehicle or the media context were reversed, the vehicle would switch modes.

A Balancing Act

Frank Bailey

I hesitate to say the following, being of a retiring nature but: There is thin water between Yacht Design and Yacht Research. Having said that, there are three reasons why this article has been written, these reasons being stated in the following three paragraphs.

A few years ago I was perambulating some sidewalks of the fleshpots of Washington D.C. and to get away if only momentarily from the cacophony of many unintelligible languages assailing my sensitive ears, I stepped into a second hand bookshop and almost at once ran across a 1954 copy of John Morwood's book "Sailing Aerodynamics" which I of course immediately purchased.

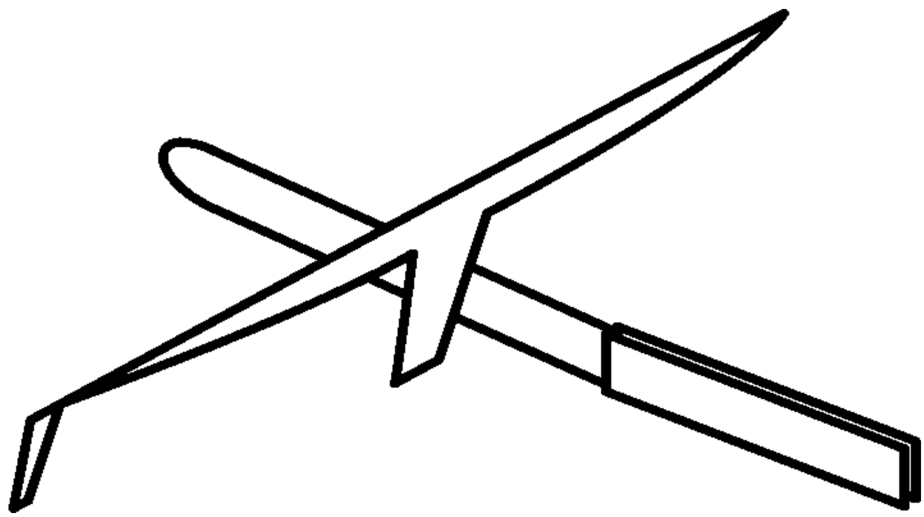
In the now dim distant past, I built a Narragansett Bay catboat, gaff rigged which had a penchant not to respond to the tiller when trying to head up into the wind. This could only be remedied (by experience) first by loosening the jib sheet and then by running up into the bow for a few seconds and racing back to the tiller. Subsequent to this loosening and running, I placed about 50 pounds plus of moveable lead inside on the keel near the bow. This worked I knew not why. Apparently the original boat sailed handily because it was loaded with fish. Realizing my great ignorance in the arcana of sailboat performance I enrolled in a mail order course of yacht design (which I flunked) but at about the same time joined The Amateur Yacht Research Society.

Last summer it occurred to me that I should try out more often the genoa on my 14-foot daysailer, which I did. With certain adjustments of the main and jib sheets, I noticed that the boat required lee helm to maintain a straight course, that is, the boat would fall off and not head up into the wind if the tiller was left unattended. Realizing this would be a fun thing to investigate, I regurgitated previously consumed knowledge and came up with the following article. Forgive me if this material may be a bit ho hum to many of you.

The problem simply stated: What should be the relationship between the center of effort of the sails and the center of lateral resistance of the underwater portion of the hull. At first thought it could be reasoned the two points should be both on a vertical line for correct balance. Correct balance would mean on most courses of sailing and rig trim the rudder is close to being parallel to the centerline of the hull. To try and figure out the sail balance of the 14-footer, I resorted to the camera and the drawing board, since I had no design drawings of the boat in question. A fairly precise side view drawing of the boat was the result of taking side view photos of the boat on its trailer with a six foot rule in some of the pictures. Thus, the photo could be scaled and dimensions transferred to the drawing. A challenge was positioning the 3/8 inch steel centerboard properly on the drawing as it could not of course be lowered while the boat was on the trailer. Previous to this current exercise I had removed the steel plate centerboard weighing 92 pounds and made a scale drawing of it. The final drawing showing the elements of balance is shown here.

I also found a recent advertisement from the manufacturer of my boat with a sailplan, main and jib, including the hull broadside with centerboard down. As a matter of interest, I found my ancient boat was about a foot shorter than the current models. Using this sailplan I wished to find what the elements of balance of this boat might be compared to mine.

With these drawings, I found the center of effort of the sailplan and the center of resistance of the lateral plane for my boat and the recent model. One could go to great lengths with a planimeter and lots of measurements to find the points of balance of sail and hull but a much simpler method is to make cardboard cutouts of each and balance the cutouts on a knife edge to get the fore and aft balance points. If you have a sensitive weigh scale available, you can record the weight of a known area of cardboard and thus figure out the area of the sails and the lateral plane by weighing the sails and the lateral plane. For the sails I used a bit of geometry



and checked the sail area by the cutout method and the comparison was very close. Since there are two areas involved with the sailplan, we must resort to a bit of simple math using lever arms to find the center of effort of the two sails combined. For example, with the mainsail of 73 square feet and the jib with 21 square feet, the center of effort of both combined is somewhere on a line connecting the two individual centers, being closer to the larger sail. This was done for jib/main and genoa/main. I only had the jib/main drawing from the manufacturer.

As stated above, ideally, the center of effort of the sails should be directly above the center of lateral resistance. In the yacht design course I took there was a table showing the desired design lead of the sailplan effort ahead of the hull center of resistance. This material has long been deep-six'd but as I recall, per standard practice, if you take the difference in the two centers from the bow waterline as a percentage of the total waterline, for different hull designs and sailplans, you get a sizeable percentage and not zero. A complication is what to do with the rudder area. I figured my percentages with and without the rudder area. The results are shown below.

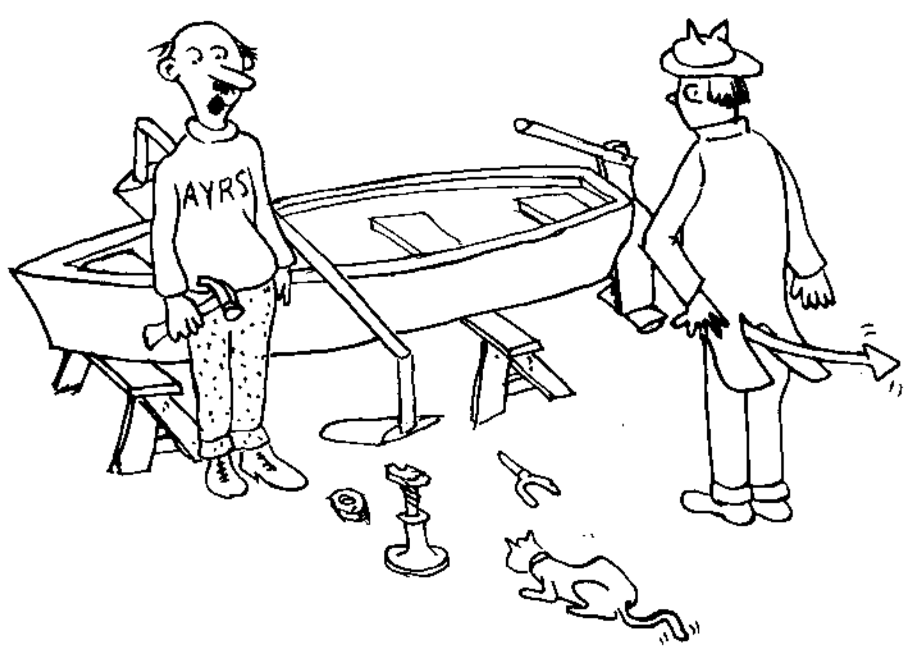
I think the results are fairly accurate, except my rudder areas may be off more than the other data. My plot and cutouts used a scale of ½ inch =1 foot. The weights of my cutouts ranged from 2 to 10 grams. Of course these results are theoretical. In Chapter VIII of "Sailing Aerodynamics", Dr. Morwood with a page of drawings of a catboat discusses quite succinctly how these centers, air and water, move around due to various sail trims, course angles to the wind, hull speed, and sail design. For instance, he states that the center of effort of high aspect ratio sails moves around less than low aspect ratio sails. The overlapping of the main and genoa is also a complicating factor. He supplies no quantitative data. For another excellent discussion of this desideratum, you may refer to Edmund Bruce's book "Design for Fast Sailing" (A.Y.R.S. publication

My Boat, center of effort ahead of center of lateral resistance		Manufacturer's drawing, center of effort ahead of lateral resistance	
Main and jib no rudder	4%	No rudder	9%
Main and jib with rudder	9%	With rudder (large rudder area?)	21%
Main and genoa, no rudder (sails overlap appreciably)	6%		
Main and genoa with rudder	11%		

No. 82), Chapter XXIII. His speculative example on page 212 just about says it all as to weather and lee helm. This aspect of sail/hull design may not be particularly important when compared with other current yacht research. I have not searched too diligently the A.Y.R.S. archives but have seen little or nothing on this subject other than the two references cited above. There may be something in A.Y.R.S. Booklet No. 5, Sailing Hull Design but I do not have a copy at hand. In the yacht design course I flunked, it was stated that data or crib sheet data (i.e. other people's data) be accumulated as to percentages of lead (if any) for various hull designs and sail plans to be used in your own designs. Some useful time also might perhaps be spent on this subject by reading some materials authored by C. P. Kunhardt, C. A. Marchaj, Francis S. Kinney (Skene's), W. J. Daniels & H. B. Tucker (models), Robert C. Henry & Richards T. Miller, Howard I. Chapelle, and D. H. C. Phillips-Birt, and no doubt some others you are familiar with, more or less more modern. I hope my arithmetic on the above is sound and my spelling close. Need it be said a bit of weather helm is desired at all time for safety?

As a result of the above analysis, I found that, again, by placing lead weights near the bow of my 14 footer, there was less lee helm (The center of lateral resistance moved forward.). Further, since my original kick up rudder support rotted (due to lack of maintenance while loaned out for a season. Never loan your books or your boats out to anyone.), I had to build a new support and rudder, the new rudder being a bit smaller than the original. It is apparent rudder size is a big factor for balance because of its long moment arm and there is data available on recommended rudder sizes as a percentage of lateral plane area. A interesting exercise could be to plot graphically a curve of rudder area versus change of center of lateral resistance for a typical daysailer, all of this being done in percentages. Perhaps the A.Y.R.S. should collect and archive some of this design data.

P.S. The following might add to the above. While cruising on a 32 footer, the Captain and I (as lowly crew member) quite often made good progress in a strong breeze with genoa only, the boat being overpowered if we put the main up as well. The wheel was attached to the rudder through gearing of some sort which no doubt took some of the load off the helmsman. The boat, being of the cruising type, probably had a long keel. Thus I would expect the center of lateral resistance would not shift around near as much as a centerboarder but still the center of effort of the jib was quite well forward creating a quite large lead. Still, the boat responded excellently to the rudder.



Pardon me sir, but I can guarantee success with your project if we first can make a small bargain.

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

October

4th - 11th Weymouth Speedweek
Weymouth & Portland Sailing Academy, Portland, UK, Contact: Nick Povey, tel: +44 (7713) 401 292; email: nick@speedsailing.com

8th AYRS Weymouth meeting
Speedsailing. 19.30 for 20.00hrs at the Royal Dorset Yacht Club, Upper Mall, Weymouth. Contact: AYRS Secretary, BCM AYRS, London WC1N 3XX; tel: +44 (1727) 862 268; email: ayrs@fishwick.demon.co.uk

November

5th AYRS London meeting on ***Ultimate Sailing - Philip Gooding*** 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

December

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

January 2004

8th - 18th London International Boat Show (dates subject to change!)
New venue – EXCEL Exhibition Centre, Docklands. Those who can give a day or two, from 15th December onwards, to help build/staff the AYRS stand (reward - free entry!) should contact Sheila Fishwick tel: +44 (1727) 862 268; email: ayrs@fishwick.demon.co.uk

17th AYRS Annual General Meeting
Venue to be announced!
Contact: AYRS Secretary, BCM AYRS, London WC1N 3XX; tel: +44 (1727) 862 268; email: ayrs@fishwick.demon.co.uk

February

4th AYRS London meeting on ***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

3rd AYRS London meeting on ***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

7th AYRS London meeting on ***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; tel: +44 (1727) 862 268; email: ayrs@fishwick.demon.co.uk

AYRS London Meetings

Please note that the AYRS London meetings at the London Corinthian Sailing Club will be on the FIRST WEDNESDAY of every winter month (Nov-April).

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

On the Horizon . . .

Quatrefoil - Jon Montgomery
Mini-Trimaran - S Newman Darby
Gravity Shift Keel - M K Mitchell
Free Spirit, a trimaran for the less-able - Charles Magnan
Weymouth reports
Kitesail Power for the America's Cup - Dave Culp
Flying Proa - Roberto Rampinelli
More sources and resources: reviews, publications and Internet sites

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BCM AYRS, London WC1N 3XX, UK

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