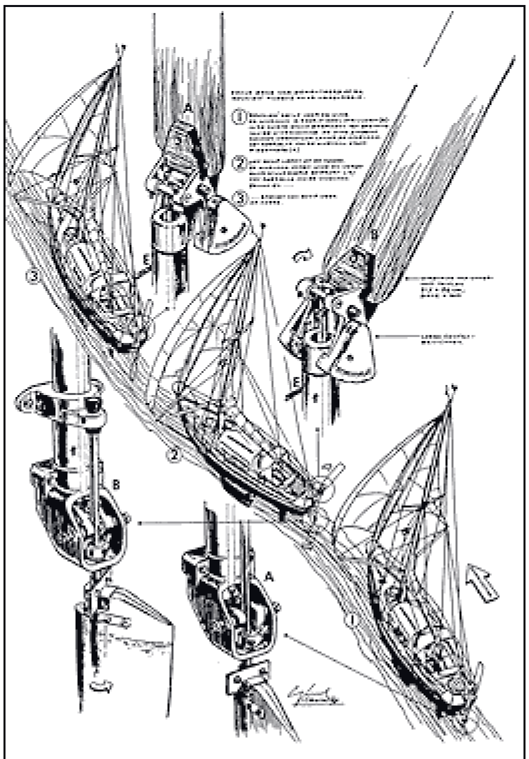
Self-Steering - By Derek Daniels

Although vane steering first appeared on sailing yachts in 1955, the development of the equipment available today began with the 1960 Single handed Trans-Atlantic Race. There have been, and still are, windvanes that function in a number of different ways. But of all of these, the servo pendulum and the auxiliary rudder have become by far the most often seen on cruising yachts throughout the world.

By making clear the principles that govern the operation of these two types of equipment, the following pages will perhaps be of assistance to anyone considering windvane steering for his boat.

Derek K. Daniels
Hydrovane Yacht Equipment Limited
Chilwell, Nottingham, England
Fall, 1984



WIND VANE SELF STEERING

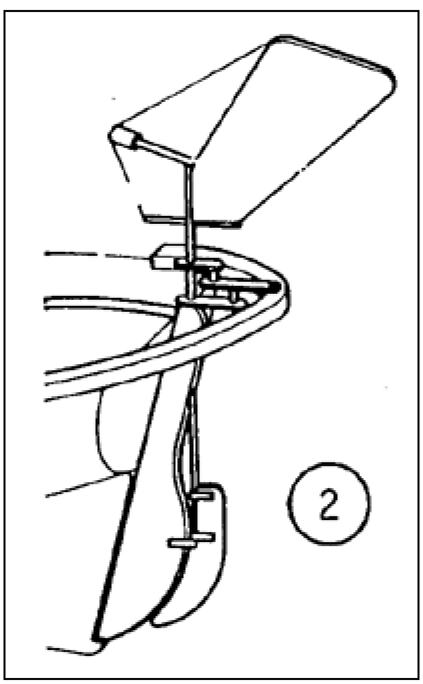
Drawing by V. Straaten, reproduced from the book by Herman Jansen "de horizon zeilde mee, dag na dag" recording his circumnavigation. The steering gear is a 1970 model Hydrovane FDA.

EARLY DAYS

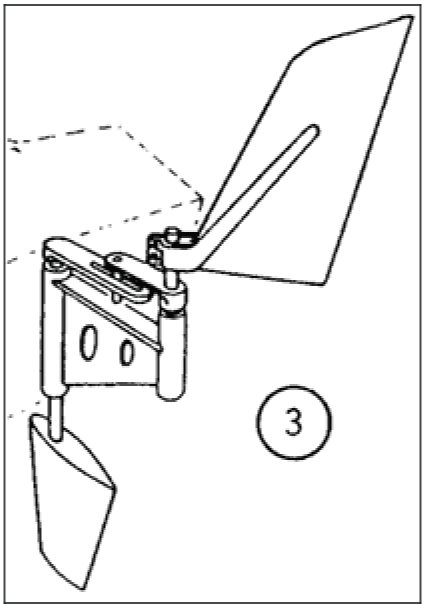
Not surprisingly, the first full size vane gears were based on those originally used around the beginning of the century to steer model yachts. The windvane moved around a vertical axis and it was connected directly to the yacht's rudder. There were therefore two main problems. Firstly, the power of the windvane was limited because, like a weathervane, it would move only by the amount of the course error - a course change of 5 degrees would be seen by the vane as a change of apparent wind direction of 5 degrees and so the vane could rotate only through this small angle in its attempt to move the rudder to correct the course. Secondly, the yacht's rudder, often unbalanced and large enough to hold the weather helm and put the yacht about, placed far too great a demand on the limited efforts of the windvane in all but the easier sailing conditions. Unfortunately the vane movement was too small to allow it to be geared down in an attempt to provide a steering force equivalent to that of the helmsman.

In light weather the vane would barely overcome the friction in the rudder system. Stronger winds, supplying more power to the vane, would increase the boat speed and the resistance from the rudder would present an equally impossible situation. These problems could only be solved by having a windvane of extraordinary size and this elementary system was abandoned.

Development of vertical axis vane gears then took two quite different directions. One was the use of servo assistance, using the power of the water flow past the hull, in an attempt once again to provide the forces needed to move the yacht's rudder. The vane was connected to a trim tab on the trailing edge of the rudder in such a way that movement of the tab by the vane in one direction resulted in the water flow pushing the tab, and the rudder on which it was hung, round in the other direction to correct the course. This seemed a neat solution to the whole problem but there were significant drawbacks. Only yachts with outboard rudders could have a tab fitted easily and the tab was quite large unless it was hung well behind the rudder to give it more leverage. Because tab and rudder turned in opposite directions, the tab area reduced the effectiveness of the rudder. Nevertheless results were encouraging and pointed the way forward for other more complex servo devices.



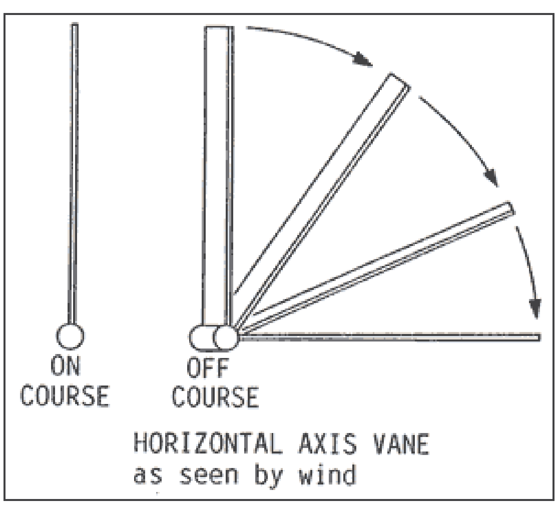
The other solution, again reducing the workload on the windvane, was to connect it instead to a quite separate auxiliary rudder. Not only could this rudder be balanced and the friction in the transmission reduced to a fraction of that in the main steering system, but it could be as small as a quarter of the size of the yacht's rudder - because the main rudder could now be used for trimming the yacht by having it fixed to carry the average weather helm. The yacht itself was now better balanced and the steering system an independent unit - an elegant solution indeed and very successful on small yachts. But of course, the larger the yacht, the larger the auxiliary rudder became until the limitations of a reasonable size of vertical axis vane were once again apparent.

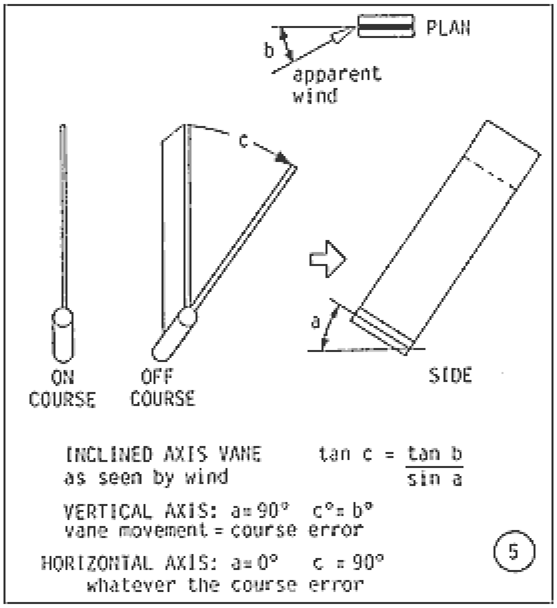


Between 1960 and 1965 two entirely novel concepts were introduced into vane gear design. In France, Marcel Gianoli proposed a system using a windvane that turned on a near horizontal rather than a vertical axis, and in England, Col. H. G. Hasler designed the first servo pendulum unit.

THE HORIZONTAL AXIS VANE

The influence of the vane axis angle on the performance of a vane gear is not always fully appreciated. Diagram 5 shows the horizontal axis vane and the vane most often used today, the inclined axis vane. In fact, all vanes are represented by the inclined axis vane - for when the inclination 'a' is 90 degrees the vane has a vertical axis and when this angle is zero, the vane has horizontal axis. The diagram of the horizontal axis vane shows that a vane deflection of 20 degrees to 30 degrees does not significantly reduce the area exposed to the wind. This vane is still at an angle to the wind even when it has rotated through 60 degrees or more. Compare this improvement in power with that of the vertical axis vane, which can rotate only through an angle equal to the course error and, in doing so, loses all the wind force.





That a horizontal axis vane could go hard over even for the smallest course error shows its great power advantage over the vertical axis vane. This power bonus, allowing the movement of such a vane to be geared down to move a much larger rudder, also brings a potential disadvantage. Whereas the power generated by the vertical axis vane is related to the course error, the vane applying the greatest correction initially and then returning the steering rudder to neutral gradually as the boat regains the course, the horizontal axis vane can easily over-react, bringing the boat back far too quickly, through the correct course and beyond. The vane must then go hard over the other way and so on.

So, it was evident to Gianoli that some compromise was needed. The inclined axis, possessing both a horizontal and a vertical component, represents that compromise. Both diagrams show the vane as seen by the wind - initially at an angle to the wind of around 10 degrees of the course error.

It is the inclination of the vane axis from horizontal that counts. Any additional angle contributed by heeling will reduce the power of the horizontal axis vane and, surprisingly, will increase the power of the original vertical axis vane. If the yacht heels at 30 degrees in a beam wind, a vane having an axis initially inclined at 30 degrees will have only the same power potential as a vertical axis vane, since the axis of each is now at 60 degrees to the horizontal. On the other hand, a vane with its axis initially horizontal, although now reduced in effectiveness, will still be more powerful than the other two - and, importantly, will be quite stable. The conclusion to be drawn is that the vane axis should be inclined, at least at little, most of the time. The vertical component of the axis will introduce the desired stability, allowing the vane to bring the steering rudder gradually amidships as the yacht regains the course.

Even today there are in print books dealing with vane steering that neglect the attitude of the yacht. A horizontal axis vane is condemned out of hand as unstable. But the axis is never truly horizontal unless the yacht is running in light conditions. Even then its capacity for drawing the maximum power from the least apparent wind will steer a balanced sailplane when other vanes will not.

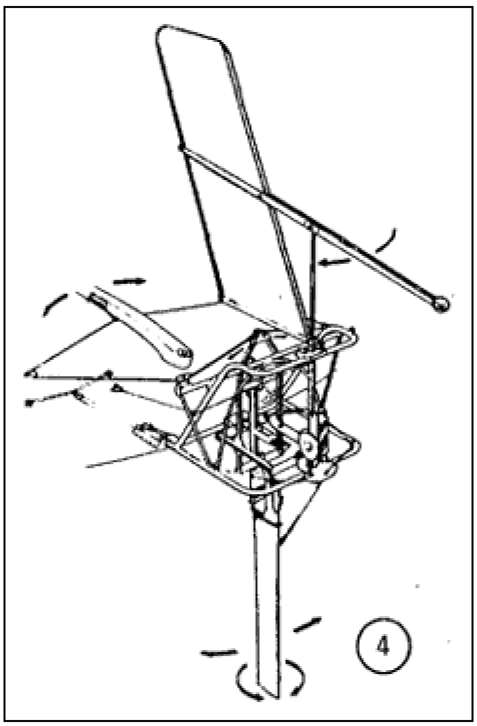
So that the power of the vane, and its stability can be adjusted to suit all sailing conditions, a variable axis angle is obviously an advantage - in light winds the vane power can be increased dramatically, as we have seen, simply by moving the vane axis nearer horizontal.

In stronger winds any tendency of the near-horizontal axis vane to over steer is removed if the axis angle is increased.

Practical considerations in the construction of the vane gear, rather than the physical proximity of stays and rigging, will usually restrict the rotation of an inclined axis vane to around 45 degrees. Even so, a course error of 10 degrees can provide a power output six or seven times that of the equivalent vertical axis vane. For smaller course errors the advantage increases greatly, improving sensitivity and speed of response.

THE SERVO PENDULUM

Like all good ideas, Col. Hasler's design, once produced, seemed the obvious solution to the problems set by the limitations of the trim tab system. The windvane turns a blade hung vertically behind the stern and the deflected blade, now mounted on a horizontal axis, is able to swing sideways and upwards as it feels the water flow. The movements of the swinging blade are connected by lines to the tiller or wheel - and so the system can be used for yachts with inboard or outboard rudders.

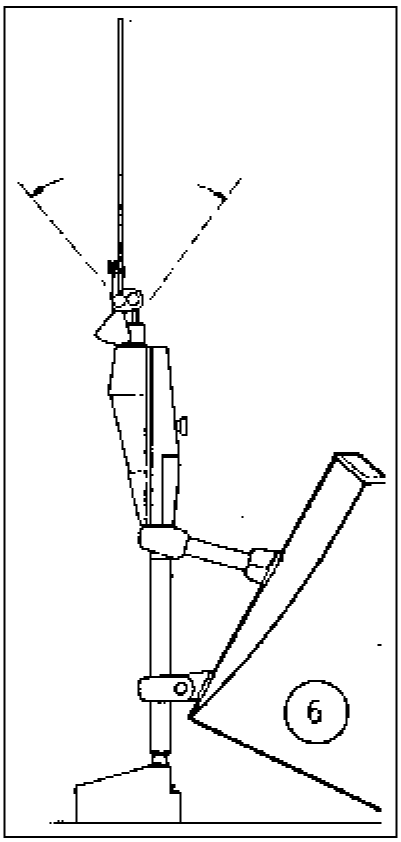


The blade can be quite small, even for relatively large yachts, because the leverage of the pendulum, from around deck level to below the water, is usually much greater than that of a trim tab - from the tab to the pintles. A pendulum is of course another form of trim tab, since both accept the force from the water flow and use it to turn the rudder. The difference is that the indirect connection of the pendulum to the rudder by lines makes it possible for the vane to turn the servo blade in the same direction as the blade turns the rudder. Therefore the blade no longer reduces the effectiveness of the main rudder. But, just like the trim tab, the corrective steering force is determined by the speed of the boat through the water.

FURTHER DEVELOPMENTS

1. AUXILIARY RUDDER - INCLINED AXIS VANE

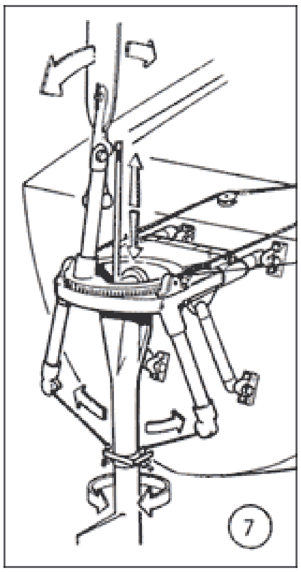
The auxiliary rudder steering gear is no longer limited in its application by the low power of the vertical axis vane. On larger yachts its advantages become even more apparent. For example, installation on a yacht with a large unbalanced rudder, center cockpit and wheel steering, does not present any difficulties. Steering lines do not have to be taken forward to a drum on the wheel. The heavy main rudder does not have to be turned, nor its inertia overcome each time a course correction is needed, and the friction in the wheel steering system is not a factor affecting the vane gear's performance. With the yacht's rudder fixed to carry the standing helm, the auxiliary rudder performs with completely independent efficiency.



To make better use of the extra power of the inclined axis vane, the large vane movements are reduced by the mechanism, increasing torque at the rudder shaft while still providing sufficient deflection. In addition, the auxiliary rudder can be almost totally balanced - and therefore very easily turned - with no ill effects. It is the inclination of the vane axis itself that controls the stability of the system, feeding power to the rudder and controlling that power.

2. SERVO PENDULUM - INCLINED AXIS VANE

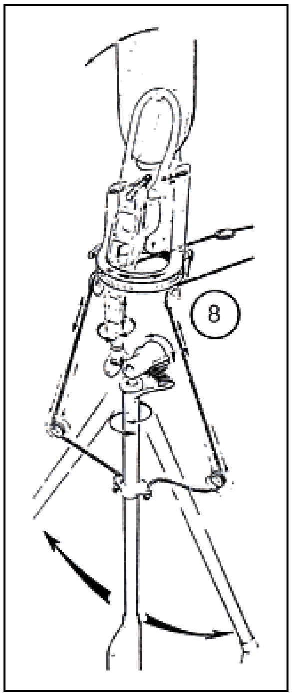
It was not long before the inclined axis vane was combined with the servo pendulum. The power advantage allows a smaller vane to be used, promoting a quicker initial response. However the sensitivity of the system is still governed by the speed at which the main rudder can be turned. This will vary from yacht to yacht. If the lines from the pendulum are taken only a short distance to a tiller operating a semi-balanced rudder, the course correction may be fast and effective. An unbalanced main rudder, wheel steering and a longer distance from the pendulum to the wheel are factors that slow down the course correction, despite the initial response of the vane.



RUDDER FEEDBACK

Because the vane itself controls the movements of a balanced auxiliary rudder in relation to the course error, the system is automatically stable. This is not so with a servo pendulum, since the pendulum blade draws on the force of the water flow to generate enough power to turn the large yacht's rudder. Although the deflection of the blade is limited by the vane movement, the subsequent swing of the pendulum requires a separate control.

A pendulum must have the power to move, for example, an unbalanced rudder on the end of a long keel. Equally it is important that a more easily turned semi-balanced main rudder should not be overpowered. The use of single pendulum design for different yachts, each with different steering characteristics, is made possible by arranging the mechanism so that the initial angle of the blade to the water flow is progressively reduced to zero as the pendulum swings. It is the movement of the rudder that counts. It matters little that the force applied may at first be more than is needed, so long as the final movement of the rudder is that required by the yacht and by the course error.



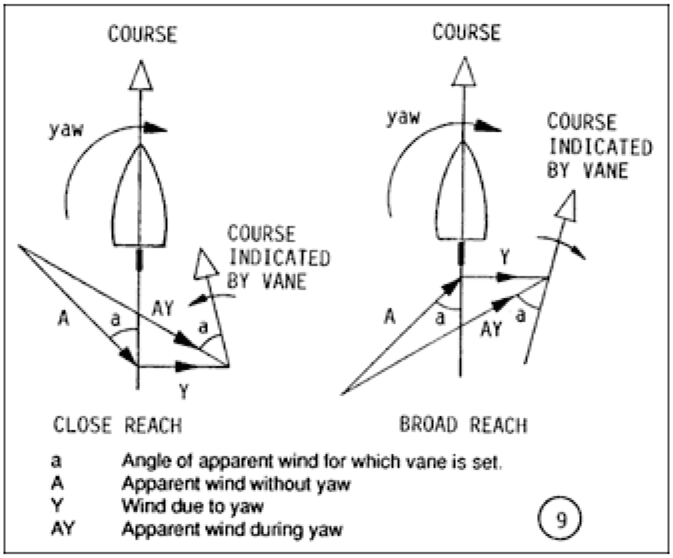
This control is referred to as rudder feedback, which means simply that an increasing rudder angle is accompanied by a reduction in the power that produces it.

Of the many ways that the pendulum swing can be controlled, the use of a pair of bevel gears for the final connection from vane to servo blade is one of the more popular (diagram 8). The bevel gears are used in the conventional way to convert the vane movement to the rotation required by the blade. Then, as the pendulum swings, the driven gear (at the top of the pendulum shaft) must rotate backwards around the driving gear (connected to the vane) and in doing so removes the rotation it has just been given. There is now a relation between the course error and the magnitude of the pendulum swing. The greater the blade movement transmitted from the vane, the greater will be the swing of the pendulum before the bevel gears return to their original relative positions, the blade is re-aligned with the water flow and rudder movement stops.

Rudder feedback is also present in the auxiliary rudder steering gear - although it is not so visible. It is simply that the movement of the auxiliary rudder is accompanied by a reduction in the power supply as the vertical component of the inclined axis feathers the vane into the wind.

CONSIDERATIONS OF STABILITY

On a close reaching course a yacht has stable tendencies. Broad reaching a monohull at least has not. But it is not this fact alone that calls for a more careful look at the requirements for good self steering. Diagram 9 shows just why the demands on a vane steering gear are more searching on a broad reach.

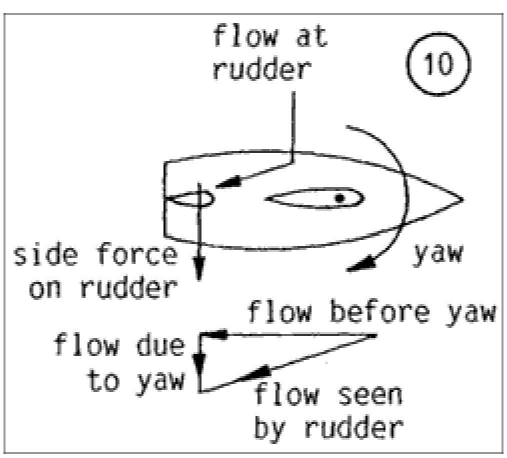


The first diagram shows the yacht on a close reach. The apparent wind is a combination of the true wind and the yacht's forward motion. If the yacht is at the moment on course but yawing to starboard, the vane now sees a new apparent wind that includes an additional component due to the rate of yaw. Although the yacht is at that instant pointing in the right direction, the vane will make a correction to port, which is just what is required to slow down the yaw to starboard.

In the second diagram, the same yacht, now on a broad reach, makes life more difficult for the vane gear. A yaw to starboard provides a new apparent wind direction which suggests to the vane that a turn to starboard would correct the course. As the yaw continues and the yacht moves off course, the vane will recognize the need to change its mind. So a correction will certainly be made, but it will be delayed.

Yawing occurs naturally as the yacht heels and the sail forces, then acting farther away from the hull, try to turn the yacht from the desired course. Can anything be done to ease the situation? For the answer we must look below the water .

Diagram 10 shows the water flow at the main rudder as the yacht yaws to starboard. Whatever the type of self steering, vane gear or autopilot, it is the large area of the main rudder that can help keep the yacht steady. If the rudder blade yields to the sideways pressure, yawing will not be countered.



AUXILIARY RUDDER

The yaw damping action of the auxiliary rudder system is easy to understand. Because it is firmly fixed when an auxiliary rudder is in use, the main rudder is unable to turn into line with the water flow. It will automatically develop a sideways force in the correct direction to resist the yaw. The auxiliary rudder, placed farther aft, produces its own stabilizing force in just the same way as the main rudder. Although balanced, with little tendency to line up with the water, its effectiveness may be modified by the yaw component of apparent wind shown in diagram 9, turning it towards the flow. Nevertheless, its contribution will be positive and, importantly, its action can never reduce the steadying influence of the large main rudder.

SERVO PENDULUM

The contribution of a pendulum to yaw damping is less certain. Let the yacht again be yawing to starboard. As a result both the pendulum and the rudder see a water flow from the port side. The rudder, especially if it is unbalanced, can be turned easily by the sideways flow. But the pendulum blade, connected by lines to the rudder, also feels the lateral water flow and should generate a force to starboard, preventing the rudder from lining up with the water. However, as with the auxiliary rudder, the wind vane itself may at the same time be trying to turn the pendulum blade the wrong way, into line with the flow, reducing its control of the main rudder - possibly leaving it momentarily free and the yacht to its own devices.

Because the pendulum is in this case the only means of controlling the main rudder, yaw damping will be positive only if the force that the pendulum can apply is at least equal to the force needed to move the rudder when both meet the lateral water flow. Yaw damping will therefore be variable from yacht to yacht, depending upon the size and balance of the main rudder.

We must be clear on one point, yawing cannot be prevented - it is a natural movement of the hull - but it can be controlled.

PERFORMANCE

Close reaching, when most yachts are relatively stable, rarely presents a problem for either type of vane steering. An auxiliary rudder will have little to do, with most of the force to steady the yacht already provided by the fixed main rudder. A servo pendulum will easily supply sufficient power if there is enough wind to keep the yacht moving briskly.

On a broad reach, as we have seen, the sensitivity of the windvane itself is reduced by the natural yawing movement of the yacht. Corrections will be initiated later because the yacht must turn farther off course to produce a change in apparent wind at the vane. If the vane gear reacts too slowly, the greater the correction must be. Speed of response is the vital requirement for broad reaching.

An auxiliary rudder has a vane and mechanism specifically designed to turn its own balanced rudder. There are no unknown quantities. Its reaction to a change of apparent wind will be immediate. However well designed a servo pendulum may be, its performance is less predictable.

The stretch in long connecting lines to a wheel, the lost energy as the lines are turned and chafed by the blocks and wheel drum and the resistance and inertia of the main rudder system will always delay its response.

Sailing downwind in light airs, a good vane gear will not be troubled by the reduction in apparent wind as the yacht runs before it. These are the conditions that dictate the size of the windvane and the balance of the auxiliary rudder. Although a pendulum blade may also be controlled by the vane, it will pick up very little force from the slow water flow, leaving the main rudder without the restraint needed to counteract the swing of the stern. For the servo pendulum, this is its least effective point of sailing.

On many steering gears a second, larger, vane is used in an attempt to overcome the problems of control in light weather. But it is important to understand that more vane area alone is not a complete solution. Reducing the vane axis angle on the other hand will promote a larger vane rotation from a smaller course error. Not only is sensitivity increased but, with more vane movement, an adjustment in the vane to rudder ratio can be made to increase the vane's mechanical advantage so that it turns the rudder more easily. Tuning the response of the vane gear in this way, to the demands of wind and sea, is the key to effective vane steering.

OTHER CONSIDERATIONS

Although an auxiliary rudder may be as small as a quarter the size of the yacht's rudder, it can certainly be used as the only rudder in an emergency. It may be necessary to reduce sail and perhaps make course changes dictated by the weather. Nevertheless a second rudder offers invaluable security. Properly constructed and with a good mounting system, it will survive the worst weather.

The yacht's rudder begins life equally reliable. Unfortunately it is not so easy to inspect the bearings of the main rudder, nor its condition generally. The tiller itself could be damaged and take some time to repair. Wheel steering quadrants, cables, chains, rod ends, hydraulics or gears all require frequent checking.

A servo pendulum, like an autopilot, makes a great many more corrections than a helmsman, often unnecessarily. The wear on the yacht's steering system is therefore considerably increased. By contrast, equipped with an auxiliary rudder, long passages are made with the main rudder stationary.

Rudder failure is too common to ignore. Many such problems are well documented. In a recent ARC report for example:

This year's ARC had the usual spate of incidents, the most serious being the decision of the crew of Amber Nectar to abandon the yacht after it lost its rudder one week after the start and hitch a ride on a tanker heading for West Africa. Three of the crew transferred to the Chevron Meteor but the skipper of Amber Nectar, Anthony Stubbs, refused to leave the disabled yacht and informed the US Coast Guard, who were coordinating the operation, that he would effect emergency repairs and that he had enough provisions on board for two months. Rigging up a jury rudder with two oars, he single-handed the 2000 miles to St. Lucia where he arrived on 29 December. Steering problems also befell the Swedish yacht Independence, whose complete rudder fell off some 500 miles from St. Lucia. The crew managed to steer a course for St. Lucia with their Hydrovane self-steering gear. They crossed the finishing line under sail, docked the yacht and only then informed the organizers of their misfortune! Their self-sufficiency was most impressive.

The possibility of connecting a low priced autopilot to the steering gear's auxiliary rudder, using less electricity, has a lot to recommend it. The system then offers hands-off emergency steering if windvane steering is for the time not possible. Downwind, when wave heights may make vane steering erratic, the combination of autopilot and auxiliary rudder could well keep the yacht under sail.

Servo pendulums are always provided with overload protection - hinge-ups, shear sleeves or other devices. Auxiliary rudders are not. Why is this?

A pendulum operates by accepting sometimes quite large forces from the water flow to generate the power necessary to turn the main rudder. But the equipment can be designed to accommodate these forces. It is against the major and unpredictable loads inflicted on the blade, shaft, linkage, mainframe and the stern itself, by the movements of the hull that require special consideration. Swung out to one side on a heavily pitching stern, the pendulum is lifted and forced downwards repeatedly into the water. The sideways loads on the blade are considerable. Usually it is the stretch in the connecting lines alone that will absorb the impact and save the steering gear - the lines that reduce its sensitivity now come to its aid. If the pendulum should be at the end of its swing and hard against a stop, only a shear sleeve on the shaft will provide a certain fail-safe. A hinge-up connection above the blade will protect the shaft only from a mainly frontal load.

When the shear sleeve fails, as it is intended to do, it will very likely be in the worst weather. Without warning there is no self steering and the yacht is now dangerously exposed with its rudder free. What are the chances of replacing the sleeve before conditions improve?

An auxiliary rudder, on the other hand, like any spade rudder, will enter the water much more cleanly as the stern comes down. Its shaft and mounting brackets must be adequately strong - just like the yacht's rudder, which of course never has a shear sleeve. Floating debris that could wreck a swinging servo shaft, will be pushed aside by the hull and main rudder, so protecting an auxiliary rudder mounted behind them.

PRACTICAL REQUIREMENTS

For the safe operation of the servo pendulum, a hinge-up facility must allow the blade to be lifted clear of the water at sea if the steering gear is not in use. In harbour it would certainly be inadvisable for the relatively fragile blade, supported only at around deck level, to remain in its operating position.

Because the shaft of the auxiliary rudder is rigidly fixed just above the water, the rudder blade can remain in place at all times. It should not be necessary to remove it at sea, so that it will always be available for emergency steering. The mechanism must permit simple disengagement of the rudder shaft, allowing the rudder to trail freely in the water flow, or be fixed amidships when the engine is used. On a well-designed unit the auxiliary rudder itself can, when required, be easily removed - so that nothing remains in the water when the yacht is left unattended for periods in port.

Installation of all types of vane steering must be strong and secure. That the hull should be reinforced at the attachment points is self evident. Fortunately the top fixing for an auxiliary rudder will usually be close to the hull/deck joint, or the backstay chain plate, where the stern is already strengthened. The lower support, near the junction of transom and counter, is equally well placed. Canoe sterns are usually very strong by virtue of their shape.

Servo pendulums are not too difficult to install either. But the attachment of the steering gear is only half the job. Lines to the tiller may be quite easy to route around an aft cockpit. Wheel steering presents quite a different problem, particularly in a center cockpit. The longer the lines, the less sensitive the equipment becomes - and they have to be long. There is no choice. Well over thirty feet of line is not an uncommon requirement. The routing of these lines can be something of a compromise between the ideal and the practical.

A standard production wheel drum may not accommodate the wheel turns required. Many mechanical steering systems offer far too much friction and hydraulic steering is out of the question.

A method of locking the wheel is the sole requirement for the auxiliary rudder. Lines across the cockpit are not a necessary inconvenience.

It must be possible to revert to manual steering without delay in an emergency. From an aft cockpit both the tiller or wheel and the steering gear will be within easy reach. On a center cockpit yacht it will be necessary to unlock the wheel drum, or disconnect the lines from a pendulum in the absence of a clutch facility. An auxiliary rudder will be over-ridden quite easily by the wheel.

DESIGN AND CONSTRUCTION

To ensure reliable operation, the minimum of moving parts will be used between vane and steering rudder. Because of the swing of the shaft, a servo pendulum has an extra stage of movement. This is not necessarily a drawback provided that the construction of the pendulum will accommodate the very high loads imposed upon it.

Bent and welded stainless tube and plate was a feature of the construction of many early steering gears. For reasons of economy or low investment, some manufacturers still build their equipment entirely this way, even though the finished appearance may leave a lot to be desired. The use of light alloy castings allows the components to be made exactly the desired shape, with thicker sections concentrating strength where stresses are higher. Stainless steel parts are still required - bolts, axles, shafts - and these can be effectively isolated from the aluminium alloy by plastic sleeves and bushes. In this way the best possible material can be used for each component. Where loads are concentrated in the mechanism, bronze castings and stainless steel can be used together without any problems.

Generally the construction of the moving parts should combine lightness and strength. Light weather performance demands it. But equipment too lightly built can easily be damaged by wave action. If repairs should ever be necessary, components bolted together are more easily replaced. A welded fabrication, straightened after damage, may then possess only a fraction of its original strength.

Friction between moving parts will be reduced, without the need for frequent lubrication, by the combination of stainless steel axles or shafts with acetal plastic bearings. The more slippery P.T.F.E., which deforms quite easily, can be used only in lightly loaded areas. An important point is that all bearings must have a generous clearance to allow for the coating of salt that will inevitably build up on the rotating parts. Salt and grit may quickly remove any advantage from more complex ball or roller bearings. So these should be used only when absolutely necessary and be protected as much as possible. Such bearings will generally be more successful if balls or rollers are without the customary cages.

The windvane itself, being the largest moving part, must be as light as possible to avoid inertia effects as the yacht rolls. At the same time its strength and stiffness must not be compromised. The rudder or blade, and the shaft, are the parts of the steering gear at greatest risk. Their construction must therefore accept loads many times greater than those anticipated.

HYDROVANE SELF STEERING

In 1968 the prototype Hydrovane auxiliary rudder steering gear was first tested on the Solent, England. It had a fixed horizontal vane axis, remote course setting and a variable vane to rudder movement ratio. During the past years we have designed and manufactured eleven different versions of that original unit. The variable ratio mechanism is still substantially the same - with three operating ratios rather than the original four, and neutral, all selected without actually disengaging the vane to rudder connection. Since 1979 the Hydrovane has been equipped with an adjustable angle vane axis of such a simple design that the facility may not at first be noticed. Together with the variable ratio, this feature allows the unit to be tuned to the response required by different yachts in any sailing conditions.

Our efforts have not been confined to auxiliary rudder gears. Trim tab units were sold for a while and servo pendulums tested. However, although more expensive to build, the separate rudder steering gear out-performs any system connected to the main rudder in the conditions that defeated vane steering for many years - running and light wind sailing generally.

Our present VXA Hydrovanes incorporate not just our own experience in design and construction for reliable operation. For the designer, there can never be any substitute for the suggestions and opinions of thousands of Hydrovane owners, sailing many different yachts - sloops, cutter, ketches, yawls, multi-hulls, - with almost endless underwater characteristics. From the shape of a major component to the clearance in a plastic sleeve, their contributions cannot be over-estimated.

Derek K. Daniels
Fall, 1984