THE APPLICATION OF VPPs TO PRACTICAL SAILING PROBLEMS

Karl L. Kirkman, M. Rosenblatt & Son, Arlington, VA

EXPERIMENTAL STUDIES OF THE SAILING YACHT

FIG. 6.—ANALYSIS OF FORCES ACTING ON A BOAT SAILING CLOSE-HAULED ON THE PORT TACK

FRONTISPICE: EVALUATION OF WINDWARD SAILING EQUILIBRIUM CONDITION

KSM DAVIDSON, SNAME, 1936
NOMENCLATURE AND SPECIAL SYMBOLS

BAW - Apparent wind angle; wind angle relative to boat heading in boat coordinates.

BTW - True wind angle; wind angle relative to boat's course in earth coordinates.

CL - Rig aerodynamic lift coefficient; see page 11.

FLAT - Amount of sail flattening; see page 11.

IMS - International Measurement System; system of handicapping yachts to account for course conditions using a VPP basis.

IOR - Intentional Offshore Rule; system of handicapping yachts to single rating.

MHS - Measurement Handicap System; former name of IMS.

PBL - Planetary Boundary Layer; see page 7.

Polar Diagram - Envelope of yacht performance as function of wind direction; see page 7.

REEF - Amount of sail area reefed; see page 11.

VAW - Apparent wind velocity; wind speed measured relative to boat coordinates.

VMC - Velocity made good along course; see page 19.

VMG - Velocity Made Good (to windward); component of velocity vector directly into true wind.

VPP - Velocity Prediction Program; a computer program for calculating sailing yacht performance.

VTW - True wind velocity; wind speed measured relative to earth coordinates.
The velocity prediction program, VPP, appeared on the yachting scene about ten years ago and it now dominates design and sailing. Originally implemented as a handicapping tool under the Measurement Handicap System, now accepted internationally as IMS, it has seen widespread acceptance for many other uses, from design to tuning and racing.

This capability means that it is productive, even necessary, for the typical sailor interested in good performance to understand how to apply a VPP to his activities. To do so requires an appreciation of how a VPP functions and how it is applied to practical sailing problems, such as sail selection or tactics.

The paper presents a review of VPP fundamentals and then treats the following applications:

- Sail selection and strategy for offshore yachts.
- Tuning and optimization of all boats

It is the goal of the paper to impart a working understanding of the VPP to many sailors so that they can take advantage of the technology in their normal activities.
HISTORICAL BACKGROUND

The genesis of the contemporary VPP is intimately merged into that of towing tank tests of sailing yachts; both have shared in some notable disappointments and combined to bring significant improvements.

Early tank tests, for example, failed to account for heel and leeway (with predictable consequences). In fact, it was K. S. M. Davidson who combined the understanding of the equilibrium of close-hauled sailing forces with appropriate test equipment, procedures, and analysis to solidly establish the validity of such tests in the 1930's.

Davidson's work is a clear demonstration of the exclusively human trait of dealing with our environment by developing an algorithm, and it also confirmed the inclination expressed by Olin Stephens cited above; in search of good model predictions, Davidson became involved in sailing trials, full-scale towing of actual yachts, and in the estimation of actual aerodynamic coefficients; the "Gimcrack" coefficients still in use and obtained by careful sailing trials on a contemporary day sailer which was also model tested at the time.

The art of performance prediction also was made possible by the appearance on the scene of the modern electronic computer in the 1960's--these were the years where the machine came into widespread availability and use in the engineering office.

Perhaps the keystone in the development was an interest in handicapping research which lead to work at MIT: the Pratt Project; led by Professors Newman and Kerwin, and named for Irving Pratt, a proponent, which is so closely linked with both the resulting Measurement Handicap System, MHS (now International Measurement System or IMS) handicapping system and a majority of contemporary practitioners as to be inseparable. For the history of that development, the reader should study carefully "The International Measurement System" by Poor, Ref. 2.

Finally, one must acknowledge the modern on-board instrumentation packages, again courtesy of the microprocessor, which make available to the casual racer a data-processing capability which was the dream of 12-meter tinkerers only a decade ago. In a paper by Charles L. McCurdy reporting this advance in "Yacht Performance Analysis with Computers" comes to mind, Ref. 3.

The combination of the insight gained by solving the windward sailing equilibrium condition equations and the speed and reliability of electronic measuring and computational capability have combined to bring a revolution in sailing. Any serious racer may now utilize a prediction of the expected performance of his yacht and a measurement of its achieved performance which are sufficiently economical and accurate to have become essential to competitive performance on the race course.

If one accepts the inevitability of this technology, then one must be prepared to capitalize on it to stay competitive--the purpose of this paper is to demonstrate some of the details of utilization.

HOW A VPP WORKS

At the same time, the force generated by the sails in a constant true wind decreases because the "apparent" wind, (that is the wind relative to the yacht) decreases, as shown on the same graph. The result is that at some speed the two will be in balance, or equilibrium, and that is the speed at which the yacht sails in those particular conditions. Of course, this equilibrium will be different for each course and wind strength. A VPP, then, calculates the prediction of the speed ("velocity") of the yacht when at this equilibrium or balance of drive with drag.

In actuality, the computation is
much more complex because it involves a balance of side force of hull and rig, stability and heeling moment, etc., but that is not important to a user to whom the calculation is invisible. To the user, only the appearance of the results matters and so some typical ones are included here:

**IMS Certificate**

The most common VPP output available to a sailor is an IMS certificate, an example of which is shown in Figure 2. The equilibrium data is shown, boxed, and includes the following under "SPEED AS A FUNCTION OF SAILING CONDITION" for six headings:

- **VTW**, true wind speed (knots)
- **BTW**, true wind angle (degrees)
- **V**, boat speed (knots)
- **VMG**, boat speed made good (knots)
- **HEEL**, heel angle (degrees)

The special meaning of these terms will be discussed shortly.

---

**Figure 1 - Sketch of Drive-Drag Equilibrium**

**Figure 2 - IMS Rating Certificate**
While the certificate data gives characteristics of the performance, it contains less information than the sophisticated sailor may be able to utilize productively, and a more sophisticated version is available in a special document called a "performance package."

IMS Performance Package

A VPP output containing additional significant data is shown in Figure 3, taken from a USYRU performance package. This summary page shows, in addition to the information on an IMS certificate, the following items:

VWA, apparent wind speed (knots)
BWA, apparent wind angle (degrees)
REEF, portion of total sail area carried
FLAT, amount of sail flattening employed
CL, lift rig coefficient

The meaning of these also will be detailed shortly.

A graphic presentation of some of this data from such a package is shown in Figure 4. This graph which is known as a "polar diagram" shows the shape of boat speed curves with heading and, as a result, shows optimum jibing angles for different strengths of wind.

HOW TO INTERPRET VPP INFORMATION

A recurring problem for VPP neophytes is the possible confusion of the true and apparent designations. It is pointless to dig further into VPPs without a solid appreciation of this distinction.

True vs. Apparent Quantities

The differentiation between true and apparent relates to the axis system of the observer. "True" velocity and headings are measured relative to a fixed location on the water surface, neglecting current; apparent velocities and heading are relative to a moving yacht coordinate axis. Thus, a yacht running at 10 knots in a 20 knot breeze would be sailing in 20 knots "true," 10 knots "apparent," the apparent wind being the difference between wind speed and boat speed. Upwind, the apparent value will be larger. This phenomenon is what leads to the common observa-
tion that the wind appears to die after rounding the windward mark or to pick up after rounding the leeward mark. A one-tonner beating in 25 knots "true" wind will experience 28 knots on the anemometer or over-the-deck and in light air the difference is larger -- 8 knots "true" will record as over 12 knots "apparent" on the anemometer.

**Planetary Boundary Layer, PBL**

One practical source of complication in measuring the wind is the existence of the Planetary Boundary Layer, PBL.

A yacht passing through the sea drags along an aftward thickening coat of water which is sheared away from the surrounding ocean and carried at speeds approaching that of the boat as one penetrates this "layer" and approaches the hull. This moving "skin" of water is called a boundary layer. In a similar manner, the encounter of wind with the earth's surface decelerates the lower layer of air so that, as a practical result, the strength of measured wind will vary with height. The way that this is dealt with is to reference wind measurements to a standard height of instrument, generally 10 meters.

This still leaves us with a number of complications in our application:

- while "wind factors" exist (see Figure 5) to translate the data to other heights, they only reflect one particular velocity distribution and that distribution can change when the weather is unusual.

- because the speed of translation of the yacht is constant with height above the water while the wind speed is chang­ing with height, the apparent wind "twists" as an observer moves aloft; right at the water surface, it is nearly dead ahead due to the PBL.

- under certain conditions, the wind direction changes with height; this is particularly true in a breeze which is in the process of filling-in or shifting -- in fact, the exist­ence of "wind shear" is often a clue to a shift in direc­tion. Indications of the existence of wind shear include the need for different sail twist tack to tack, differ­ent boat speeds tack-to-tack and seemingly inconsist­ent masthead instrument readings.

**Best VMG**

The skill of a good helmsman, when working to weather, has traditionally been that intuitive ability to sense and maintain a trade-off between excessive pointing (and commensurate low speed through the water) and excessive driving (and commensurate extra distance sailed); the optimum choice of this trade-off results in the best speed made good, in a vector sense, toward the next mark. In VPP parlance, this speed, identified as velocity made good (VMG), is important in any condition where the fastest path to an objective is not achieved by sailing directly toward it; beating is one case.

Consider, in a vector sense, one's speed starting at the cross in Figure 6 and employing different strategies. In this case, they are chosen to be silly in order to demon­strate the point.

Strategy A is to put the boat on a reach, its fastest point of sail, which covers a great distance but has no vector component toward the objective; VMG = 0.

Strategy B is to set a spinnaker and run off resulting in a nice boat speed, VB, but vector progress away from the mark or a negative VMG. This should be filed away for future refer­ence in looking at down-wind tactics, but is useless here.
The best strategy of those pictured is "C". The sails are sheeted in and the boat proceeds toward the mark with a beneficial VMG, the vector component of VB toward the mark.

A slightly more technical way to look at these strategies is shown in Figure 7 where the situation in Figure 6 is shown as a graph and length of the arrows is selected to match the speed of the boat through the water.

The full evolution of such a diagram is in Figure 8 where all possible strategies are shown and the envelope which encloses them also is shown, dashed. This is the yacht's polar diagram for one wind speed, and when the envelopes from each of a number of wind speeds are combined, we see that a plot similar to that shown in the previous Figure 4 which is from a performance package would result.

This brief discussion introduces the terminology and graphics typically associated with VPP outputs. It now remains to show how to acquire and utilize such information.
The acquisition of VPP information for a specific boat involves two aspects:
- Predictions of the anticipated performance of the yacht
- Measurement of the achieved performance on the water.

It is the comparison of these, and what is done when they do not match, which is useful to the sailor. The two aspects are treated separately below; however, a few words about failure to match and VPP accuracy are in order first.

There will be two distinct sources of failure to match:
- Measurement and processing problems
- Failure to achieve predicted performance

It is my experience that the former will be troublesome but then will be pretty much permanently put behind the user.
Anticipated Performance

The most common means of acquiring a prediction of your yacht's predicted performance is to apply for measurement to the IMS system administered by USYRU. When a boat is measured to IMS, a certificate is issued which contains sufficient data to construct a useful polar plot. An example of such a certificate is shown in Figure 2. Be aware that, while hull measurement is a necessary part of IMS rating, data on so many "standard" hulls exists that certificates can be produced for many stock boats economically. A list of the current inventory of such designs is given in Figure 9. Such certificates are so economical as to be useful to non-IMS racers in comparing performance; in fact, grand-prix IOR race boats sometimes get IMS measured solely to acquire a polar and the more complete performance package; I am aware of both IOR racers who are doing so and PHRF racers utilizing the standard hull data.

Less common are various proprietary services who will prepare an equivalent presentation which, while not useful as a rating, can help do design trade-offs or assist in sailing the boat. Some of these are advertised as exceeding the quality of an IMS certificate in predictive ability; it is the experience of the writer that such claims represent more of a distinction than a difference except for unusual circumstances.

When the performance anticipated is made part of an on-board instrumentation package so as to present comparisons to the crew in real time, usually in the form of a custom "chip" in a microprocessor, the purveyor of such packages is in a position to suggest a source of the data with which he has had good experience.

Measurement Instrumentation

It should, at this point, be clear that the utilization of technology such as discussed in earlier sections implies the availability of hard measures of some of these quantities: boat speed, wind speed, heading, etc.

This need not be as intimidating an investment as a complete instrument package although such may well be justified. Without getting into that issue for now, let us consider a representative sample of choices.

On-board. Without doubt, the system most commonly utilized by an individual sailor would be one with all transducers and processing equipment on-board and with results available in real time to the crew.

A rather minimum package would include boat speed measurement and apparent wind speed/direction measurement which when integrated could be used as the most basic monitor of performance. It should be emphasized that any such system will require a significant calibration effort if it is to be at all useful in a quantitative sense; that is, if the performance of one's boat is to be seriously compared to any standards of performance for improving race results.

A next level of sophistication could involve integrating a standard of performance into the package for comparison with measured boat performance; some systems are sold with a "canned" speed polar (which as a result probably has had its accuracy compromised appreciably) or the interfacing of a custom polar is possible to provide target performance data, as mentioned above. The data contained in a USYRU IMS measurement certificate is widely used for this, even by yachts which do not race under IMS.

To take the system a step further could involve the interfacing of instruments in the tactical/navigational area. A digital compass and a LORAN are good features of this type which, when interfaced, allow the relation of performance data to race course issues, time to the mark or layline, track error, etc.

This writer once raced a fairly large yacht somewhat seriously and with some success without so much as a speed measuring device, but if picking an instrument system in today's environment would find the maximum package of features mentioned above to be cost effective for competitive sailing.

Further enhancement is available in a couple of directions:

- The provision of a data processing/logging capability which can permit specialized/sophisticated performance monitoring and a permanent record of actual performance, either for archival purposes or diagnostics.

- The integration of boat tuning data into the central system, namely: stay tensions, vang tensions, control system geometry (rudder and tab angles), etc.

While this may seem more suited to a 12-meter campaign than to an individual racer, that may not be correct. For example, if the monitoring of headstay tension allowed for
instantaneous and repeatable best sail shape, the cost of that feature is much less than a special purpose sail with a limited wind range; the effect over a season potentially much more significant.

Over-the-side. Although not suitable for the individual racer, the use of instrumentation off the boat is a common method of performance monitoring.

One approach is telemetry of data to a tender or shore base for analysis or storage, and this has now been a part of a number of 12-meter campaigns.

A more powerful tool is the fitting of a complete monitoring system aboard a tender which has the following advantages:

- Calibration is much more straightforward and instrument errors due to their proximity to the rig are avoided; downwash, heel and leeway corrections vanish.
- The weight, space, power consumption, and distraction of performance monitoring are taken off the boat.
- The tender can serve as a portable "trial horse" and can be operated to emulate various other boats with the assurance that it is being "sailed" to its potential.
- The tender can assist with a diagnostic review of race performance or a coaching tool.

The preceding information shows how to acquire measures of expected and achieved performance, but has yet to deal with adjudicating differences. That process, which is the heart of successful application, now follows.

HOW TO UTILIZE VPP INFORMATION

The methods for utilizing this newly acquired predictive data and instrument package include the following categories:

- Guidelines to improve boat speed.
- Guidelines to utilize polar diagrams for faster race times tactically.
- Guidelines for strategic decisions.

Improved Boat Speed

One fundamental decision to make is related to how much sail to carry in the conditions, and how to shape that sail.

REEF AND FLAT

All of us have learned from experience that at some point in increasing wind, it is counterproductive to maintain full sail on a yacht and that a reduction in area, reefing, makes the boat go faster. Similarly, we have learned that for a given sail, the increase in sheet or outhaul tension, such as a flattening reef, improves speed. Perhaps the reasons for this are not clear, but a VPP provides for these phenomenon in the computations which can be useful to the sailor.

To understand this trade-off, consider the case of a modern jet airliner with its complex flap mechanisms. When we push back from the terminal and roll out for take-off, the pilot extends a myriad of complex leading and trailing edge hardware which are equivalent to putting a lot of camber in a sail. After take-off and climb-out, the pilot retracts all of this complex hardware and flies in a "clean" cruise configuration. Let us examine why he does this. At take-off, the objective is to get maximum lift force out of the wing, max coefficient lift, "CL," with no regard for the drag penalty. When flying at altitude, the pilot now wishes to maximize the efficiency of producing lift or lift to drag ratio, "L/D." Similarly, in a yacht, when stability is no problem, we go for maximum force, CL, and don't worry about L/D. As the breeze comes up and stability begins to come into play, we must change this trade-off.

The performance package data gives a clue as to what to do, see Figure 3. The last three items are, respectively: "REEF, FLAT, and CL," and these represent a notional sail area, how much it is flattened to trade L/D for CL, and the operating CL value. I have prepared a graph, Figure 10, which shows how well the VPP "REEF" compares to the total sail area of a yacht with well-tested sail
combinations. The agreement seems good enough to encourage you to make just such a graph for your boat; a table that shows how to do so is in Figure 11.

In looking at the reef and flat data in Figure 3, note that the VPP advises flattening the sail on a 52-degree reach in wind as light as 12 knots and reefing on this same reach in 20 knots, but not when beating!! Information of this type should be utilized to guide decisions such as whether to carry a chute on a close reach, or which size to carry, and although it may not be correct in an absolute sense, it can tell you a lot about the tendencies of your boat. Another area of judgment is sail trim and helming which are dealt with below.

![Figure 10 - Comparison of Actual and Predicted Reef Value](image)

![Figure 11 - Chart Showing How to Calculate Reef](image)
TARGET SPEEDS

Especially when sailing out of the company of other yachts, it is good to have an indication of how well we are matching our potential speed. Boat speed is not an adequate measure for reasons which are clear if you study Figure 6; using boat speed would lead to reaching.

The measure which takes into account pointing ability is VMG and this can be processed by many on-board instrument packages. However, experience shows that this is not the best to use; luffing up gives an immediate improvement, for example, yet it is not a good long-term strategy to maximize speed—indeed, VMG is usually too unstable to use as a guideline.

Those with experience have settled on using "target" boat speeds as described in the following manner:

"Target" speeds are a goal to shoot for in the existing conditions which, by means of a VPP, are known to result in the best performance while racing. Thus, the entire crew should be appraised of the targets and should work in teamwork to achieve them.

It is important to confront a huge roadblock at this point: use of target speeds implies acceptance of a lot of more-or-less invisible technology on faith; this obstacle is only overcome by exposure and accompanying success. However, to use this technology, the crew must include members who understand the underlying technical aspects and the availability of high quality instrumentation, thoughtfully installed and calibrated. This final point cannot possibly be overstated. This writer has almost invariably encountered a measure of skepticism when introducing this type of approach to a new user; successful and experienced helmsmen are correctly reluctant to suddenly cede such matters to a bunch of electronics and computer programs. With the same frequency, however, most users after a season of familiarity admit to their skepticism and acknowledge that use of the approach was the single largest performance improvement they recall, and was of major importance in their racing success. The consistency with which people recognize and acknowledge this value is striking.

Returning to target speeds, they are useful in the following ways:

- to allow for guidance in sail selection, reefing and trimming.
- to promote teamwork between helmsman and sail trimmer to deal with changes in conditions.

In a later section, some transient applications will be discussed.

In the beating application, it is accepted that a boat sailed too high will slow down and a boat sailed too low will, although going fast, not achieve good performance. Some helmsmen utilize the jib tell-tales to confirm this trade-off, but what if the jib is trimmed wrong? The use of targets involves a graph such as Figure 12 or the table containing the same data posted in sight of the helmsman and sail trimmers. By adjustments in pointing angle and sail trim, the team works toward the target speeds. As an example, if the boat is exceeding the target speed for conditions, the helmsman should head up slightly while the sails are trimmed; if it is too slow, the sheets should be started slightly and the boat brought off slightly. Experience has shown that the target speeds work well in encountering a chop or seas and should be maintained, accepting the wider sailing angle which results.

None of this means that targets should be accepted blindly. They should be checked against your own experience with the boat and modified in tactical situations such as pinching off a competitor to windward.
To summarize the loop:

1. Check the true wind speed.
2. Find out if you are sailing too fast or too slow.
3. Work between sail trimmers and helmsman to get "in the groove."
4. Go back to the beginning, check the wind speed, etc.

Although the description above has emphasized windward sailing, a similar pattern governs off-wind sailing.

Jibing Angles

A product of the VPP is the tabulation of so-called jibing angles, the off-wind headings which result in optimum performance on running legs of a race. In essence, the payoff in light air which can accrue to heading up and building apparent wind velocity more than compensates for the extra distance sailed, and this advantage disappears as the wind builds. I would suggest that the jibing angle also could be a powerful teaching or coaching tool.

As a practical example, consider the data shown in Figure 13 which was taken by an instrumented tender during an actual CBYRA Race Week Race; in this case, the yacht was not utilizing on-board instruments to optimize performance. In the early part of the leg, the yacht was doing quite well and sailed into a clear lead by mid-bay on this leg which started out as a broad reach. The wind then lightened and shifted North and the crew did not react appropriately; the data are those labelled "late part of run near Bloody Point." The yacht then promptly dropped, in a mile or so, to a mid-fleet position. If this yacht had been equipped with true wind instruments and had utilized jibing angles and target speeds, their finish position in this race probably would have improved significantly. Discussions with the skipper afterwards indicated that he considered his light spinnaker as suspect when running, yet I find the data a compelling argument to reconsider the jibing angles.

One should recall that all objectives lying along a line perpendicular to the wind and within the jibing angles are equally far downwind in the same manner that windward marks are equally far upwind. This means, referring to Figure 4, that the jibe mark in an Olympic course in light air involves virtually no extra distance sailed than if one were to sail at optimum speed directly to the leeward mark.

As a general guide, I have observed the following characterizations of individual off-wind sailing habits regarding jibing angles:

- The impossibility of relating to true wind when on a yacht without a true wind instrumentation conversion capability I recommend using apparent wind angles as a guide. The rule of thumb that I use is that the apparent wind angle with the stern is roughly twice the true wind angle.

- Absolutely huge losses in a race due to poor planning of leeward mark approaches vis-a-vis jibing angles, particularly when tidal effects predominate, and a stubborness to modify a bad plan by last minute extra jibes.

- An unwillingness to trust VPP predictions respecting jibing angles for a phenomenon which is incredibly hard to judge with constant changes in wind speed and direction.
I suggest a small graph of the type shown in Figure 14 carried in the cockpit to govern down-wind sailing, and the use of target speeds.

![Graph of downwind target speeds](image)

**Figure 14 - Graph of downwind target speeds**

**Dynamic Effects**

Most of the discussion to this point has dealt with the VPP in a steady or quasi-steady context. Sailing is not so straightforward, however, as environmental conditions are most notable for change. The most obvious result is that actual measurements may show some scatter—and this should not be taken to undercut the value of the information. Typical scatter in actual measured sailing data is shown in Figure 15.

Far more profound are the implications of the shiftiness of wind on sailing tactics and strategy, a factor which seems to be well recognized; and on sailing a boat under conditions of nonequilibrium, which does not seem to receive adequate attention.

Consider the actual race-course data in Figure 16, which was taken during the recent MacMillan Cup Regatta off Annapolis. These data are graphs of wind speed and direction at one-minute intervals measured aboard the Committee boat. If you were to come out early to a race start and sit while collecting similar data, you would detect two distinct types of variations:

- **Persistent shifts** - Caused by long-term changes in the weather systems; these would be evidenced by a gradual change in mean wind direction (Figure 16, Race 2), or sudden change in mean wind direction (Figure 16, Race 1).

- **Oscillating shifts** - Caused by mixing conditions within the weather pattern and evidenced by back and forth shifts about a mean wind direction.

It seems to be effective to use the trends of a persistent shift and the limits of oscillating shifts as cues to an effective strategy on the race course.

Of equal importance to the shifts in direction are the oscillations in velocity, also shown in Figure 16. The long-term trends are useful in sail selection, but the short term shifts in velocity have a much more profound implication—the boat is rarely sailing in equilibrium! This means that either upwind or down, the sail trim and helm angle are rarely correct for the conditions for longer than an instant; more importantly, it shows what large gains are possible by properly dealing with nonequilibrium conditions.

The most commonly recognized version of such a change is the "velocity header"; the true wind drops causing the apparent wind to go ahead. An inexperienced helmsman, or one who does not recognize the situation, is
inclined to bear off and in light air can sometimes sail a scallop to leeward chasing his apparent wind trying vainly to bring it aft.

Let me now summarize the correct strategy to apply to velocity shifts utilizing the information offered by a VPP and the concept of target speeds taken more or less directly from Reference 5.

"Upwind - Velocity Header or Lull"

1. Wind suddenly decreases.

2. Apparent wind goes forward.

3. However, you have excess speed for the new true wind velocity. Instead of bearing off to the header, steer slightly up
and trim slightly at the same time, taking advantage of the excess speed to gain VMG and performance. The helmsman should tell the trimmer: "wind speed down; trim slightly as I coast. New target speed is ___ for the new breeze."

4. As the boat speed slows, start bearing away while easing the sails, so that the new boat speed reaches the target for the new wind velocity. As the boat speed approaches the new target speed, the helmsman should call out: 'boat speed closing on target, ease sails for new breeze.'"

A sudden increase in wind produces a velocity lift.

1. Puff arrives, you feel velocity lift.

2. Don't head up to the lift, but steer straight, ease sheets and accelerate to new target for increased true wind velocity.

3. As you reach new target speed, trim for upwind settings, and turn slightly upwind to match new wind angle for increased breeze."

Again, this is a powerful short-term enhancement. As soon as you approach target speed, make sure you are approaching close hauled trim. Don't get caught sailing at or above target speed below your close hauled course, as that will cost you valuable upwind gains.

The cumulative, long-term effects of reaching the new desired target as quickly as possible will gain you the best performance while the wind is changing, and give you the maximum possible VMG and performance for the entire period. This is a tremendously valuable and important concept and sailing technique, and requires constant helmsman, trimmer, and crew coordination. It is the sum of these constant gains which will give you a performance edge that wins races.

**Downwind**

Velocity shifts downwind may often be the source of substantial gains and should be accommodated as follows:

"Lull. Decreases in true wind speed cause velocity headers. Proper response to velocity decrease-header-downwind is:

1. Bear off, maintaining constant sail trim, and use speed in excess of target speed to sail down.
2. As boat speed decays, start to head up so that boat speed reaches target for the new true wind speed.

Proper response to velocity increase-lift-downwind is:

1. Head up slightly and square spinnaker to new apparent wind angle.
2. Accelerate towards new target speed.
3. As you accelerate, apparent wind will go forward, ease the pole forward, trimming the spinnaker, enhancing the sails' performance. This allows the boat to accelerate even more rapidly.
4. As you approach new target, bear away to achieve new target at new true wind angle.

Don't bear off immediately to a puff; your response should be:

1. Apparent wind angle will further increase, and you know that it is difficult to accelerate sailing very low angles downwind.
2. Because you end up low and slow, apparent wind does not come forward as fast, and boat speed struggles to get to target."

**STRATEGIC USE OF VPP INFORMATION**

Perhaps the most widely ignored power of a VPP is in matters of long-term strategy.

**Design**

The use of VPPs as a design tool to test the rating of an alternative against its predicted performance is not novel and deserves no more than mention here. As an interesting aside, it was the custom of some designers to use ratings under another rule as a check on designs in the past and so the use of IMS to check IOR, for example, is not new.

**Race Preparation**

One area which seems to have received little attention is the tuning of a yacht's handicaps to that
of expected conditions and of the expected handicaps of opponents. Until post-race handicapping is widespread, and the certainty of this is questionable, such preparation should be considered in the following ways:

- To configure one's boat in a way that will be likely to take advantage of the handicapping as affected by wind strength. For example, if one were persuaded that a reasonable predictability existed that a race or series would not be sailed in the preannounced handicapping conditions, one might modify a boat to anticipate this. Being measured with small headsails if heavy air is expected is an example.

- To configure one's boat in a way that will place its best performance-to-condition area just slightly on the side of an important opponent toward the expected weather. In any prehandicapped race, level rating such as 12 meters or one tonners, single rating such as IOR or PHRF or prerace VPP such as IMS, it is possible to sail in conditions not anticipated by the rating; in fact, it may be likely that one would do so. As a result of this circumstance, each individual entrant may be optimized for performance-to-rating of some particular condition not at the likely expected value. If one can determine the expected speed of a boat using a VPP and the rating, one can then juxtapose himself slightly to the favored (i.e., expected weather) side of a prominent opponent. Examples of such attempted manipulations were frequent in the America's Cup Challenger Trials.

Race Strategy

Illingworth, in his 1949 book "Offshore" (Reference 6) was one of the first to publicize this aspect of use of a VPP although he did so using his intuition about polar performance as VPPs were not then widely in use.

He called attention to the following factors which now are more or less routine on the best yachts, but were then revolutionary:

- Maintaining Speed Rather than Course. In a lengthy discussion accompanied by Figure 17 reproduced from the book, Illingworth introduced a concept now espoused in the literature as velocity made good toward the mark, VMC, and gave specific advice on how far to drive off with particular rigs and hulls for best speed and what sort of distances to a mark allowed one to not sail for it. He suggests, for example, that a mark within 25 miles must be sailed for close-hauled unless there are strong indications of a change and, in general, marks 40 miles away must be sailed for close hauled lacking the specific expectation of a change.

An example of this problem repeatedly presents itself to local CBYRA races in the Solomon Island and Governor's Cup races. Both start in the evening off Annapolis and head down the Bay, frequently in a light southerly with the expectation that it may eventually shift west, yet at the start the rhumb line indicates a beat to weather. These races are frequently won by the boat that slacks sheets and reaches down the Eastern Shore (while her classmates beat faithfully to windward) and then finds herself further than they are down the Bay and lifted to Hooper's Island or the Potomac River mouth.

SAILING OFF ON A CLOSE FETCH

**Assumptions**
- Close hauled: close hauled at 6 knots
- Sailing 1 point off: 5.5 knots
- Sailing one point off: 6.5 knots
- Longships to Fastnet: 1.5 knots

**Diagram 5**

**FIGURE 17 - FIGURE FROM ILLINGWORTH'S OFFSHORE**
The strategy of VMC involves using one's polar diagram to select a point of sail which gives the yacht's maximum progress toward the mark at the sacrifice of some separation from the nominal rhumb line. A typical polar plot showing the concept is given in Figure 18, reproduced from Reference 5, which should be consulted for a much more complete description of the phenomenon. What this actually represents is a rational basis for deciding what Illingworth was forced to do by intuition.

In the limit, such problems could be treated as a weather routing phenomenon, using a probabilistic approach to expected conditions and the boat's polar to determine, in real time, appropriate strategy to exploit such information with an on-board computer. A discussion of this discipline is covered in Reference 7 and is recommended to the reader who wishes to take this aspect further.

**SUMMARY**

The velocity prediction program, VPP, is now an integral part of the technical aspect of yacht racing, and will be mastered and exploited by the successful competitors.

The use of the VPP as a design tool is of limited practical importance to sailors beyond an understanding that such use now makes possible more rational trade-off studies for boats and elements of hull and rigs than was possible previously.

Similarly, it is not essential to understand how a VPP works to exploit one for your boat but, on the other hand, insight almost always is accompanied by practical application and improvements; it doesn't hurt!

The VPP has a widespread use in handicapping as it forms the basis of the IMS rule and is utilized to improve both IOR and PHRF systems.

The best first step in utilizing a VPP aboard your own boat is in sail selection and trim and in achieving the best performance under the conditions. The concept of target speeds is primary and must be studied and tested.

The next level of sophistication is to study and apply the dynamic applications since the wind is virtually ever-changing on the race course and performance breakthroughs are possible when these concepts are practiced and refined.

Finally, VPP applications to starting tactics and navigation is yet another field of great opportunity, as yet largely not reduced to practice on any analytical basis.

**REFERENCES**