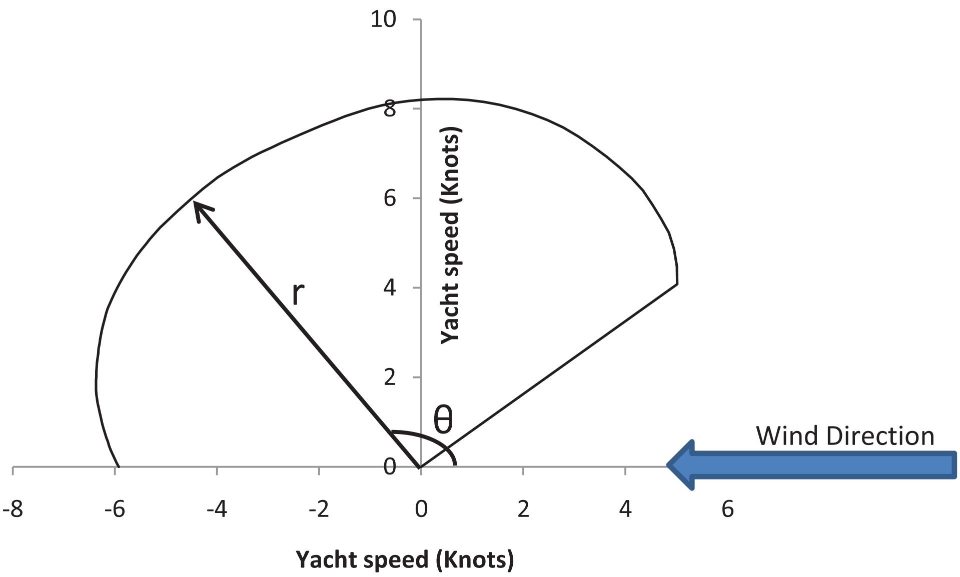
1 Formula used in the Current VPP Method

Figure 1 shows an example of the plot used in this paper. The angle, θ, is the yacht heading. The distance, r, is the yacht speed. The x and y axis units are in knots. The polar plot is symmetric about the x axis.

Figure 1 - Polar Diagram Example



The terminology for yacht headings is given below,

Close Hauled/Windward	$27^{o} – 60^{o}$
Close Reach	$60^{o} – 90^{o}$
Beam Reach	$90^{o} – 120^{o}$
Broad Reach	$120^{o} – 150^{o}$
Running	$150^{o} – 180^{o}$

4.1 Validation with Real Life Data

A Yacht VPP is model of the performance of a yacht in real life; therefore the only real validation can be against real life data.

When recording data on a yacht the following procedure is suggested;

4.1.1 Data Gathering Method

A set of readings are taken at even intervals. The interval time depends on the length of voyage and the rate at which the environment is changing. An Atlantic crossing can have intervals hourly, whereas a race can be 10 minutes. It is important to have even intervals to avoid biased results.

The following readings are taken,

- Wind – Apparent wind Speed and Direction (relative to the yacht's heading)
- Yacht – Speed through the Water
- Sail Settings – Reefing, sail combination
- Sea State – Wave Direction, Height, Frequency: Using 5 point scale

To analyse the data,

1. Categorize data according to wind speed
2. To avoid large variations in performance remove extreme state condition data
3. Produce the polar plot using wind direction and yacht speed
4. Create separate lines on the polar plot depending on the sail settings

The procedure was tested with a yacht in the Solent (Isle of Wight). Due to variable weather and short voyage time, not enough data was gathered. It was also difficult to record the wave conditions. The conclusion was that a much longer voyage is required for relevant data to be gathered.

A Yacht named Dinah, Figure 19, crossed the Atlantic and recorded wind speed, direction and yacht speed via a computer, plus data such as depth and GPS position from other yacht instruments. The route is plotted in Figure 20.

Figure 19 - Dinah In Cobh Harbour

Figure 20 - Dinah's Crossing 05/07/09 - 02/08/09

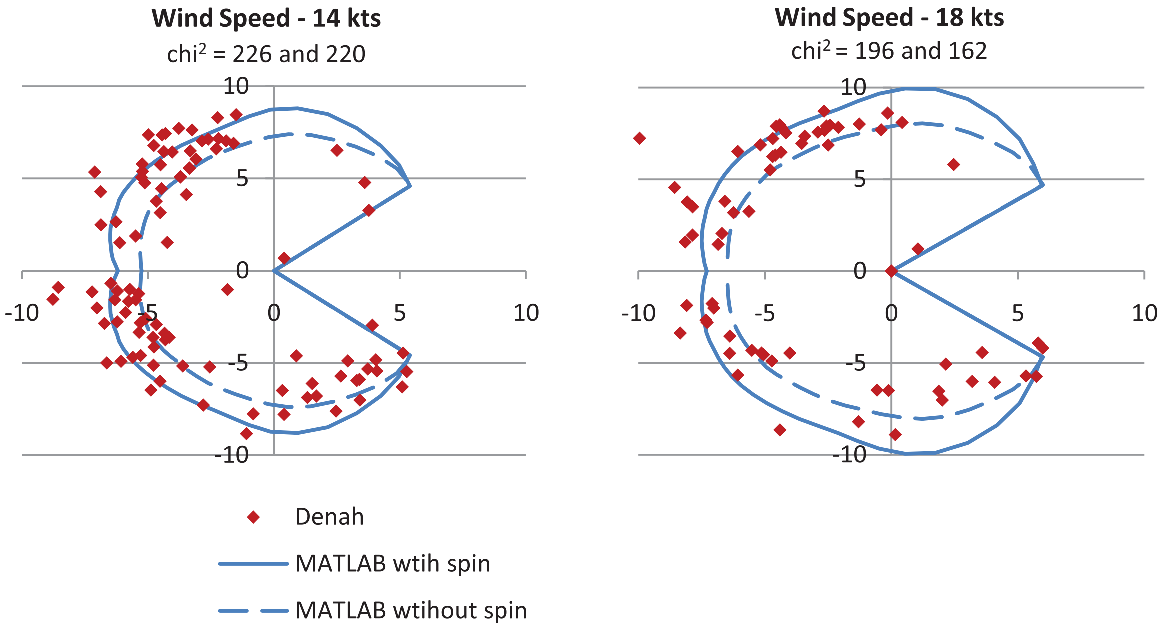
Although the data does not include wave height or sail setting, there is a large quantity of data and the author considers it is enough to make valid comparisons.

4.1.2 Results of Real Life Data Validation

The yacht is a Jeanneau One Design 35 and it is possible to obtain the principle particulars. However, there is very little to do other than estimate the remaining variables in order to run the VPP. The keel, rudder and rig dimensions were extrapolated from pictures, using ratios. The GM was estimated using the Dellenbaugh angle [4 p. 52]. The values and calculations are given in Appendix E.

Over 300 data points were separated into Wind Categories (to the nearest knot). There are no records of sail combinations, but it is assumed that the yacht sails with and without a spinnaker. The VPP therefore calculated the two combinations. A sample set of results are shown below in Figure 21. The full set can be seen in Appendix E

Figure 21 - Real life data compared with MATLAB VPP



4.1.3 Discussion of Real life Data Validation

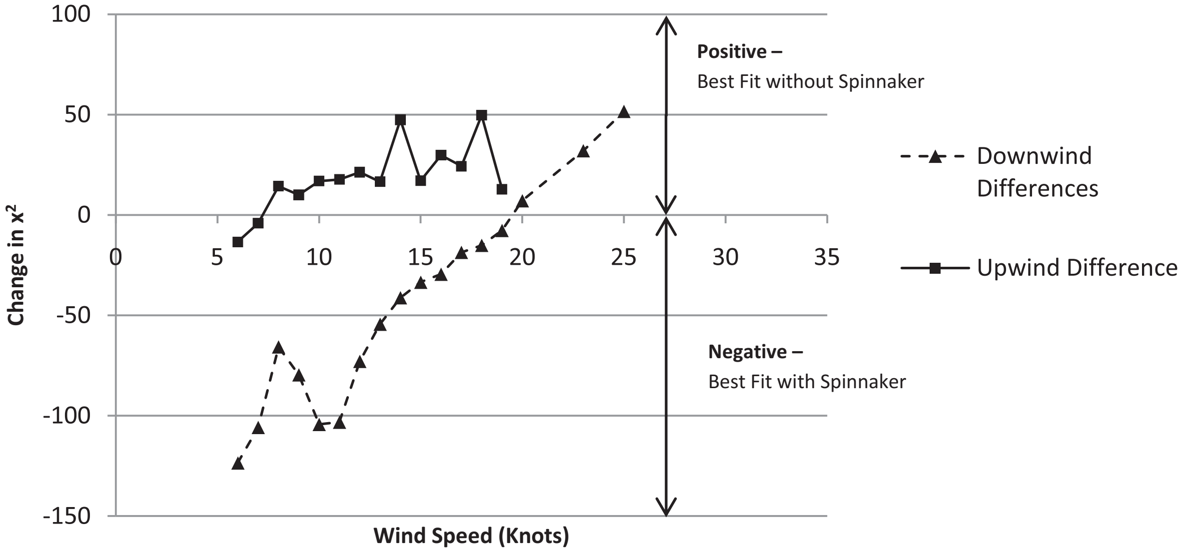
Over a wide range of wind speeds, the MATLAB VPP correlates well to the experimental data. A Chi-square (x^2) analysis has been performed on each data plot in order to quantify the fit. In all cases, the uncertainty is set to 1.

The results of the Chi-square analysis are shown in Appendix E. The values range from 50 – 200 which is very good considering the assumptions and errors associated with the VPP and the real life data result (performance in waves are ignored). This shows how robust the model is and proves that it can calculate the performance of a yacht to a reasonable degree of accuracy.

It can be seen in Figure 21, that when close hauled, the data points are closest to the non-spinnaker line. When the yacht is running downwind, the data points are closer to the spinnaker line.

This was investigated further by separating the data points into two categories; downwind (>90^o) and upwind (<90^o), then calculating chi-square for the spinnaker and non-spinnaker lines, to obtain four sets of values. The lower the value the better the data fit, therefore by taking the differences between the values for spinnaker and non-spinnaker and then plotting against wind speed, Figure 22, a comparison can be made. Results are presented in Appendix E.

Figure 22 - Chi-squared Investigation



1. The upwind difference is always positive which corresponds to a better fit to the non-spinnaker line, this is what is expected, as the spinnaker will not sail at this angle.
2. When sailing downwind with true wind speed of 5 to 13 knots, there is a large negative change in x^2 which shows that the data fits the Spinnaker line.

These observations have proven what was found in section 3.2.2.1 which is that the spinnaker prediction upwind is incorrect. The reasons behind this error could be within the lift and drag coefficients of the sail or perhaps there is a loss in lift due to heel which has not been taken into account.

3. After 20 knots the upwind data stops. On this Atlantic crossing, the skipper has avoided sailing into the wind.
4. There is a strong correlation in the downwind data from about 10 knots onwards. This positive gradient represents a decreasing correlation of the spinnaker, approaching zero at 19 knots of wind. At this point the chi-squared values are equal, and neither with or without spinnaker fit best.

This is not because the model has over predicted the performance, but because in strong winds it is unlikely that the yacht would be sailing downwind, with a spinnaker. Otherwise the yacht would be over powered and out of control.

The chi-squared analysis has identified a statistical way of identifying the point at which the skipper decides not to sail downwind with the spinnaker; the point in real life is more likely to be around 25 knots (force 6). The value is heavily dependent on the accuracy of the program and so it can be suggested as a way of validating the program.

For this program, the value is calculated to be 19 knots and so it under predicts the wind speed by 6 knots. With an improved model, this can be recalculated and should shift the graph to the right. This will be an effective way to quantify the development of the program.

4.1.4 Conclusions of Real Life Data Validation

There is very good correlation between real life data and the MATLAB VPP.

By modelling the two sail combinations in the VPP and then calculating the fit to the real life data, it has been possible to identify in what conditions the spinnaker is being used, and at what point the skipper has decided to sail downwind to avoid head seas. This is significant considering that the only relevant information provided was the apparent wind speed and direction, and yacht speed.

The analysis of the real life data has proven that the VPP has not modelled the spinnaker correctly upwind, which was first identified in Section 3. This may be due to either the Lift and Drag coefficients of the sail model or a loss in apparent wind due to heel.

The crossing point at 19 knots is a very good estimate of the point at which a skipper would take the spinnaker down. In reality it is more likely to be at 25 knots and so with an improved VPP the line should shift to the right and will be a way of quantifying the validity of the program.

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