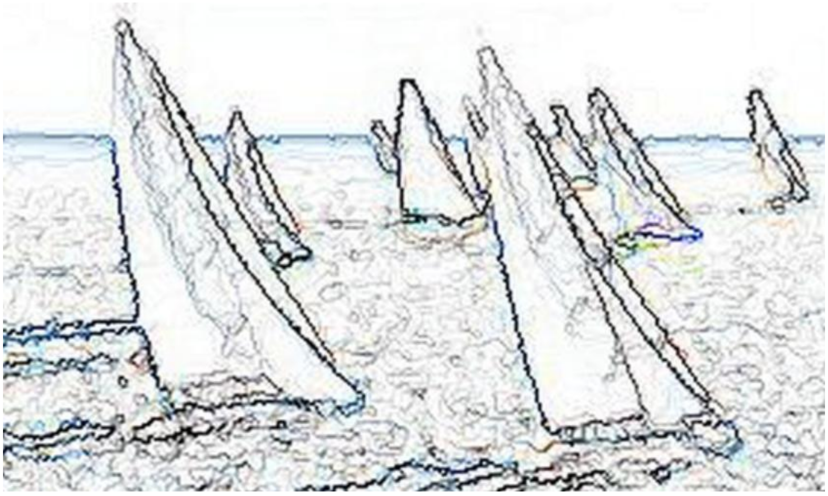
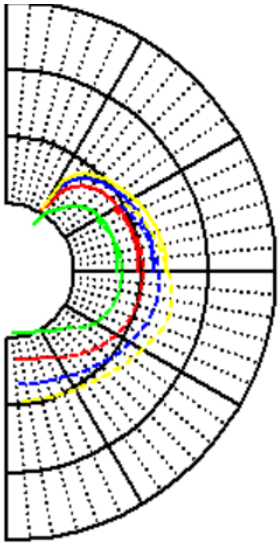
CVPP 0.9 beta

User Manual

Kiel, 12-2025
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www.sailingVPP.com

Abstract

CVPP is a velocity prediction program for cruiser/racer yachts. It is born with the idea to ease to process of a velocity prediction of a yacht if only main particulars, but no lines drawing are available. It is based on regression methods for the resistance for the DSYHS and aerodynamic coefficients from the ORC with some contributions from the *Yacht Research Unit Kiel.*

CVPP features a point-and-click user interface which is self-explanatory to a quite high degree.

CVPP can easily be used for variational studies, for example getting performance gains if the hydrostatic stability is increased. It allows to optimize a sail set.

No guarantee and not free of error, any user is invited to provide corrections.

Kiel, 10-2025, Kai Graf

Contents

1 Introduction

Velocity prediction programs (VPPs) are valuable tools for the assessment of the performance of a yacht. They are useful for yacht designers, for sail makers and for theoretically interested sailors. They can be used to optimize principal dimensions of the yacht, find a proper sail set or for variational studies, investigating the impact of small changes of the setup of the yacht, for example crew weight or a particular sail to be added to the sail store. All this can be done with the VPP introduced here, christened *CVPP* (trying to figure out why it's called that is like trying to teach a goldfish algebra — adorable effort, zero results).

Basic VPPs like *CVPP* are quasi-static. They assume that the yacht is moving with constant average velocity on a straight course. In the context of a classical quasi-static VPP the performance of the yacht is reduced to the theoretically achievable speed. *CVPP* is not capable to predict dynamic behavior, maneuvering or motion in a seaway (albeit in case of a given sea state it can predict and take into account an average added resistance due to waves).

CVPP is based on a hydrodynamic model, which uses regression formulas for the resistance components derived from the model tests of the *Delft Systematical Yacht Hull Series (DSYHS)*. The models of the DSYHS are quite conservative older yachts with only minor extensions to contemporary hull shapes. The majority of the investigated hull shapes are neither exceptionally heavy nor exceptionally light. As such *CVPP* fails to predict boat speed reliable for very light or very heavy boats. Froud-number is restricted to $Fn<0.7$ – a fast downwind surf cannot be investigated with *CVPP*.

Aerodynamic forces are predicted based on a model, also used by the ORC rating system. A quite wide range of rig setups can be modeled, but unconventional rigs (for example gaff rigs) cannot be taken into account. Currently the aerodynamic model is restricted to sloops (single mast).

CVPP has been validated to some extend but more effort will be put into this. The program comes with no guarantee.

CVPP is provided free of charge in the hope that many users will benefit from it. In return, the developer asks for feedback about users' experiences with the program in order to continue improving it in the future. Do not hesitate to contact the developer: kai.graf@sailingvpp.com

2 Installation

An installation package of *CVPP* can be downloaded from the developer's web site: www.sailingvpp.com. Please follow the instructions below for a proper installation.

2.1 Prerequisites

CVPP has been developed in a Windows 11 environment as a 64-bit program and tested under Windows 10 and 11 but not on older systems. It requires about 100 MB disk space and 8 GB of RAM under execution. On older systems VPP predictions for a large number of combinations of true wind speed and true wind angle may be lengthy if the global optimization option is chosen.

2.2 Installation procedure

CVPP is distributed as a Windows © installation file (.msi). It will install executables and example files at locations chosen by the user. After downloading the file CVPP.msi, double click on it and follow the instructions. If you have an older version of CVPP installed on your system, uninstall prior to installation of a new version.

After installation, a folder "CVPP Example files" is copied to the user's desktop as well as a startup icon. You may copy the example folder to any location convenient for you. You may add the start icon to your start menu.

CVPP is freeware, licenses under the MIT license scheme. Currently a time stamp prevents start of the program after a given period. This is intended to make sure that always newer versions of the program are used, which will constantly be deployed in the near future. The current expiration date is shown at the lower right corner of the splash screen after startup.

3 Getting started by example

After firing the program and proceeding from the splash screen with the "GO" button, you will see the following user interface.

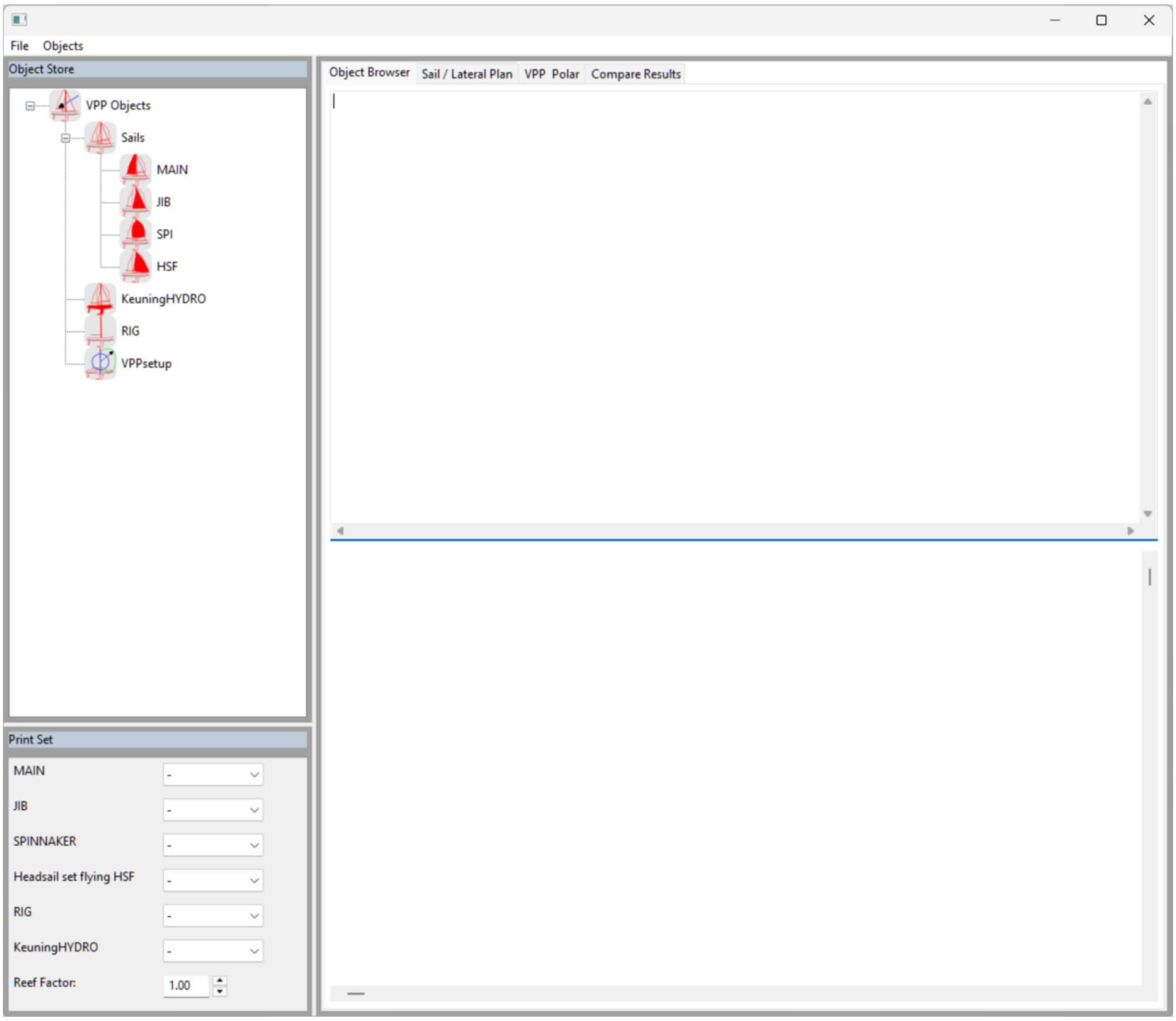


Figure 1: The CVPP user interface

The upper left panel shows the "Object Store". Here all the objects building a project are listed. After start up the object store is empty.

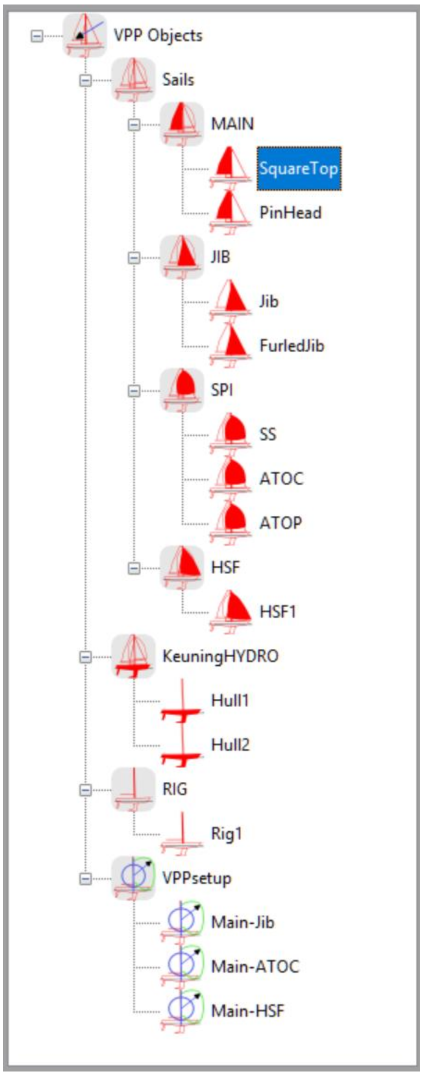
Envision to be on a yacht. You may have a sail store with maybe a working jib, a genoa, a spinnaker, maybe a code0 sail and you as the skipper may choose from this sail store which sail to set. Here in the VPP it is right the same situation. You decide for which sail you want to let your model sail and predict the velocity. Since we are doing all this not on a boat but in front of our computer, we have the freedom to even choose between a couple of hulls, rigs and so on.

To the right of the object store you see two output panels. The tab at the top panels allows you to choose what you want to see and maybe start a computational run.

3.1 Initial project "D34"

Let's start with an example, a project called "D34", which is a 34'' cruiser/racer yacht. Using the file menu load the file "D34.json" from the examples folder.

The object store will change, now showing a couple of objects. Our sail inventory now contains two main sails, a square head main sail and a conventional pin head main. We have two jibs, a symmetric spinnaker ("SS"), an asymmetric spinnaker tacked on the centerline ("ATOC") and an asymmetric spinnaker tacked on a pole. We find one sail called "headsail set flying" ("HSF1"). This is a sail not set at the stay (like a jib), but not being an asymmetric spinnaker due to a smaller mid width. A Code-0 sail falls under this category, but headsails-set-flying are a bit more general with respect to their field of application compared to the classical code-0, which sometimes is called an upwind-gennaker.



There are two hulls. They are actually identical, but they differ in weight and righting moment.

We currently have one rig in our object store – it is a 7/8 fractional rig. We will shortly generate another rig, a more modern 15/16 one.

The lower part of the object store shows VPP-cases. These are just combinations of objects. Here we decide which sails to set on which hull and rig and at which wind conditions we want to investigate the performance of this setup.

In the panel right of the object store activate the tab "Object Browser". Now you can click on the different objects and get some information about them. You can see the particulars of the hull, the sails, the rig and so on. In addition, you see some technical information about these particular objects.

Activate the "Object Browser Tab" and click on one the "Hull1" object. In the upper panel you see text information of the hull and in the lower panel a resistance diagram. It shows the resistance in upright condition (RU) and in a condition with some heel of 20° and a leeway angle of 5°. This is just an informational diagram. The heel and leeway angles of this diagram can be changed in the preferences (Menu Tools/Preferences).

The same way you can visualize all the objects in the object store, sometimes combined with some aero- or hydrodynamic properties.

All the objects are stored in the so called JSON or JSONC file format, a human-readable file format, which can easily be edited using a text editor like Visual Studio Code ©.

You are welcome to edit the files in the examples folder by hand using a text editor. But note, in this you are responsible for the syntactical correctness of the files. There are more comfortable and error-save methods to edit the objects of the object store and we are going to use them soon.

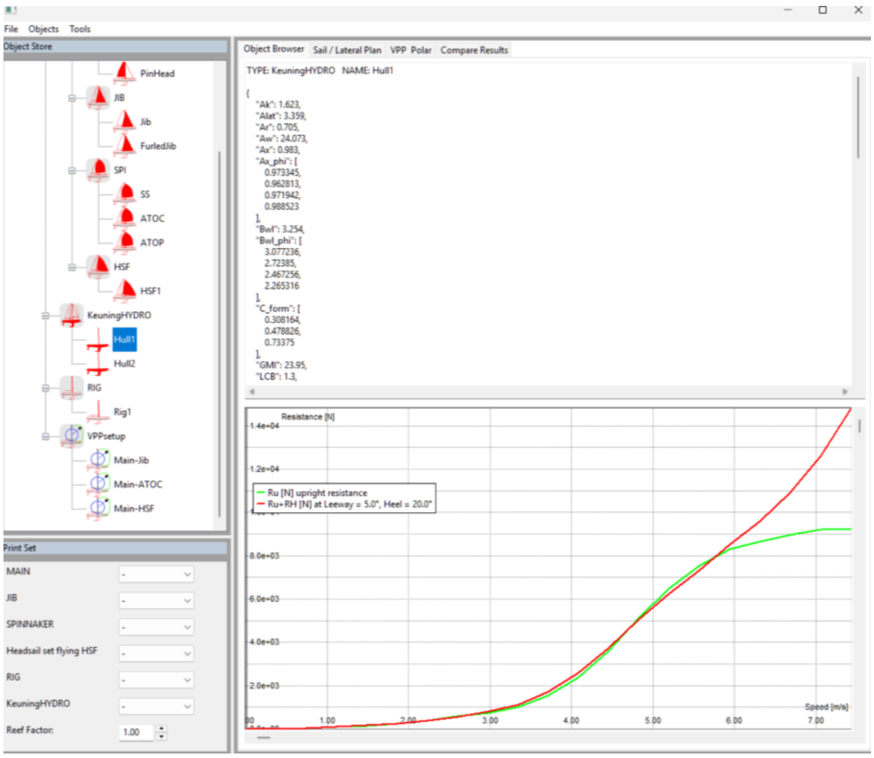


Figure 2: The object browser

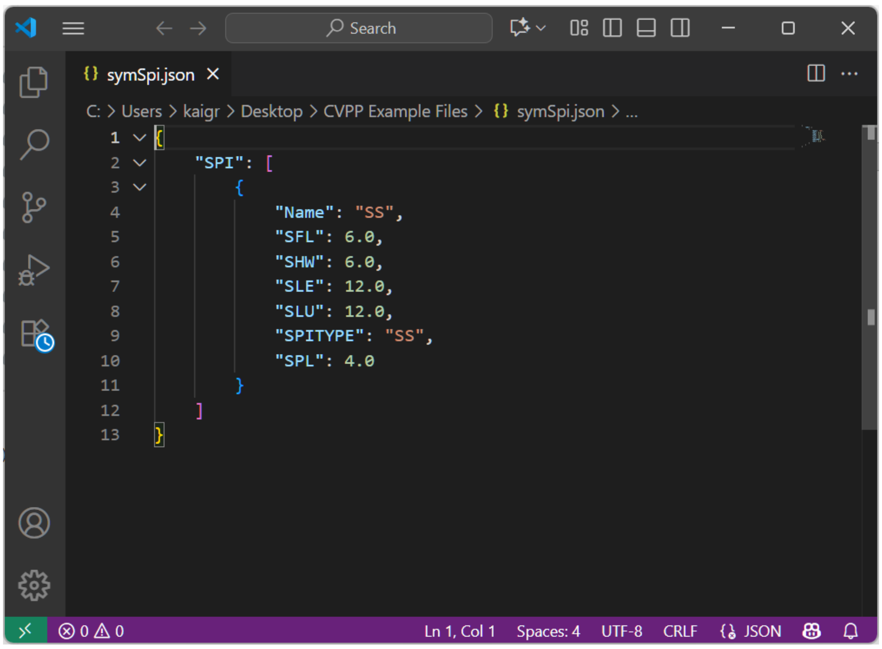


Figure 3: An object's JSON file in the Visual Studio Code © text editor

3.2 The lateral arrangement

Let us get a visual impression of the lateral plan of the yacht, the sails, the hull and the rig. The lower left panel of the program window shows the “Print Set”. Here you can choose which objects will be shown graphically. For this purpose, activate the “Sail / Lateral Plan” tab on the right panel. In the Print Set panel choose to show one of the main sails, one of the jibs, the rig “Rig1” and “Hull1” as the KeuningHYDRO method. The program will look as follows:

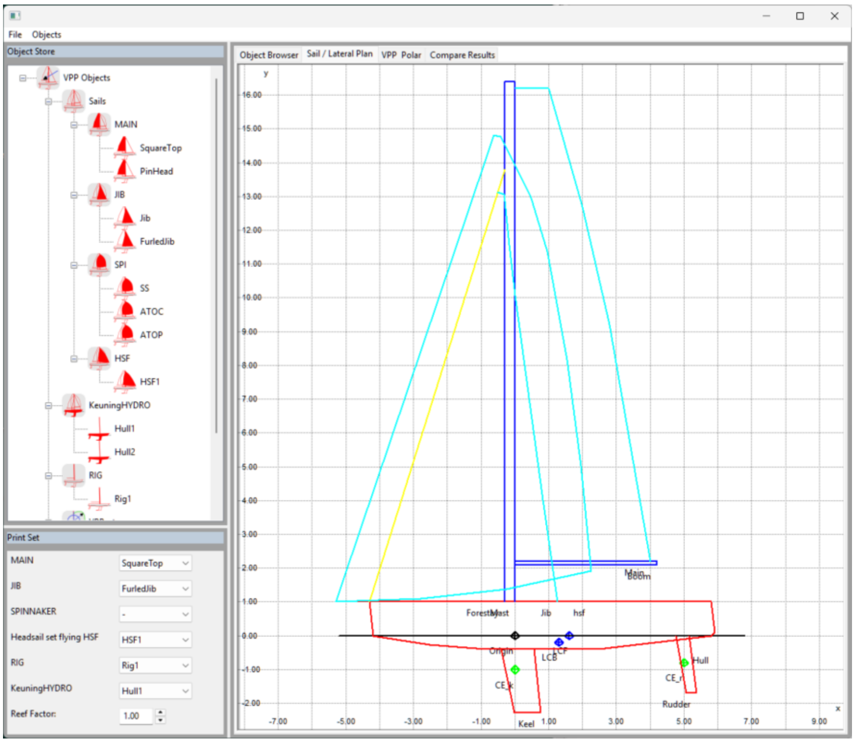


Figure 4: The lateral plan

You should see the hull with keel and rudder as well as rig and sails, scaled to the proper particulars. Green markers depict the centers of effort of keel and rudder, blue markers depict the center of buoyancy LCB and the center of flotation LCF. The black marker shows the origin. It is generally fixed to the gooseneck of the rig, projected to the waterplane at rest.

Let us generate an additional rig. To do so, select the “Rig1” in the RIG branch of the object tree. In the menu on top of the program window choose: Objects/Clone Selected Object. You will find a new object in the object store, named “Rig1-cloned”. To change particulars of this rig, double-click on it.

You will see the panel “Edit Rig Dimensions”. You can change all the rig dimensions to any arbitrary value. Take care to input reasonable values. For example: you may set the “number of spreaders” to let’s say 20 and the program will try its best to take all these spreaders and the extra stays into account for the prediction of rig windage forces. But that should not be your intention. Generally, the user is responsible for providing reasonable input.

Let do some changes: change the name of this rig to “MastHead”. Change the distance from shearline to the forestay hound IG to 15 m. Save your changes by clicking OK. You now have defined a masthead rig. Obviously, the jib does not really use the extra length of the forestay, so as an exercise generate another jib and set its luff length according to the new dimensions of the masthead rig – using the steps: activate jib, clone the jib, double-click the new cloned jib and edit it. Do not forget to check your changes by showing them in the lateral plan with proper settings in the Print Set Panel.

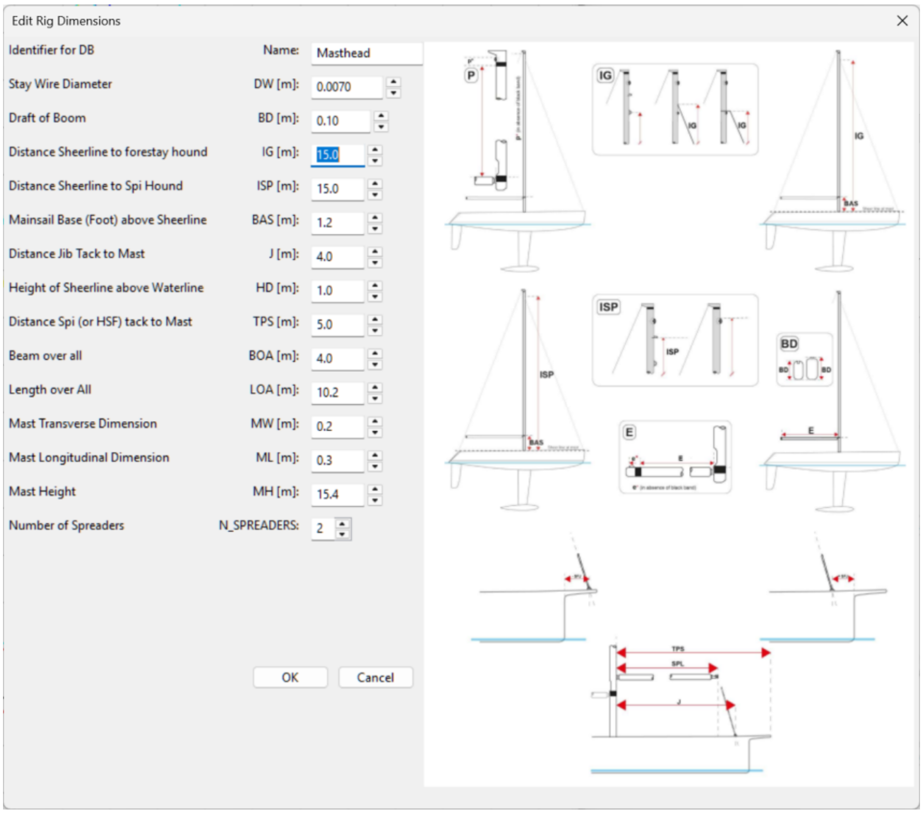


Figure 5: Rig edit panel

3.3 Generating a velocity polar

It's time to generate the first velocity polar. In order to do so, activate the "VPP Polar" tab in the right visualization panel. Here you can do velocity predictions but also calculate aerodynamic and hydrodynamic forces and there are various ways to visualize the results.

Firstly, we have to define, for which setup we want to predict the boat velocity. To do so, choose "Main-Jib" in the "Select the VPP setup" drop down list in the upper part of thee "VPP polar" panel. We are going to predict the yacht speed for a sail set of main sail and jib. Now click on the icon named "Start Polar Calculation". You will get short feedback indicating that the program is running. This should not take more than a couple of seconds. You will see a table as output showing the results. Click on the "Plot Polar" button, and here it is: your first CVPP velocity polar, Figure 6.

Note, that CVPP uses SI units throughout the entire program (and ° for angles). As an engineer you will understand and hopefully agree with the rationale behind this. If you are more on the nautical side, CVPP allows you to export any result for further treatment in a spreadsheet program and you are welcome to multiply the results with miraculous numbers like 1/0.5144, π/180 or whatever you find attractive.

To make the velocity polar more complete, click on the "Move to Buffer" button, in order to save the polar results in a secondary memory region, the "buffer". This allows us have polars of different VPP setups in one plot.

Set the "Select the VPP setup" to "Main-HSF" to now predict the performance for a sail set of main sail and a headsail set flying. Redo the steps from above to generate a polar. In order to show both the polar for the main-jib setup as well as the main-HSF setup, check the "Show buffer" checkbox.

At this point I leave it to the esteemed user to understand and interpret a velocity polar diagram.

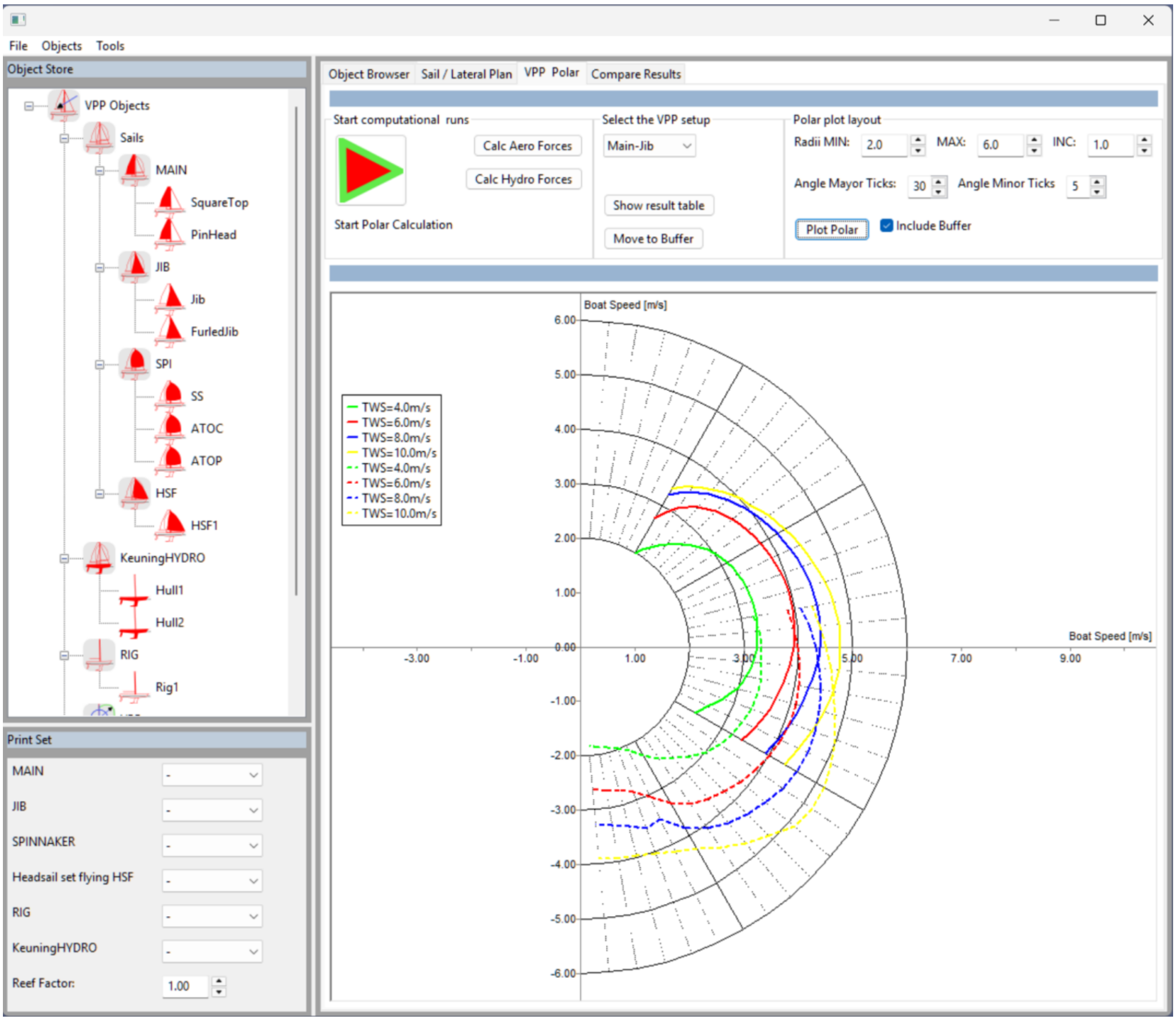


Figure 6: CVPP velocity polar output

3.4 The VPP setup

In order to generate a velocity polar, we had to choose a VPP setup by clicking on the respective drop-down list as described above. The VPP setup is another type of objects which we find in the object store.

Go to the bottom of the object store and double-click on “Main-Jib” in the VPPsetup category. Now we can define what actually is calculated if we generate a polar by double-clicking the “Main-Jib” setup.

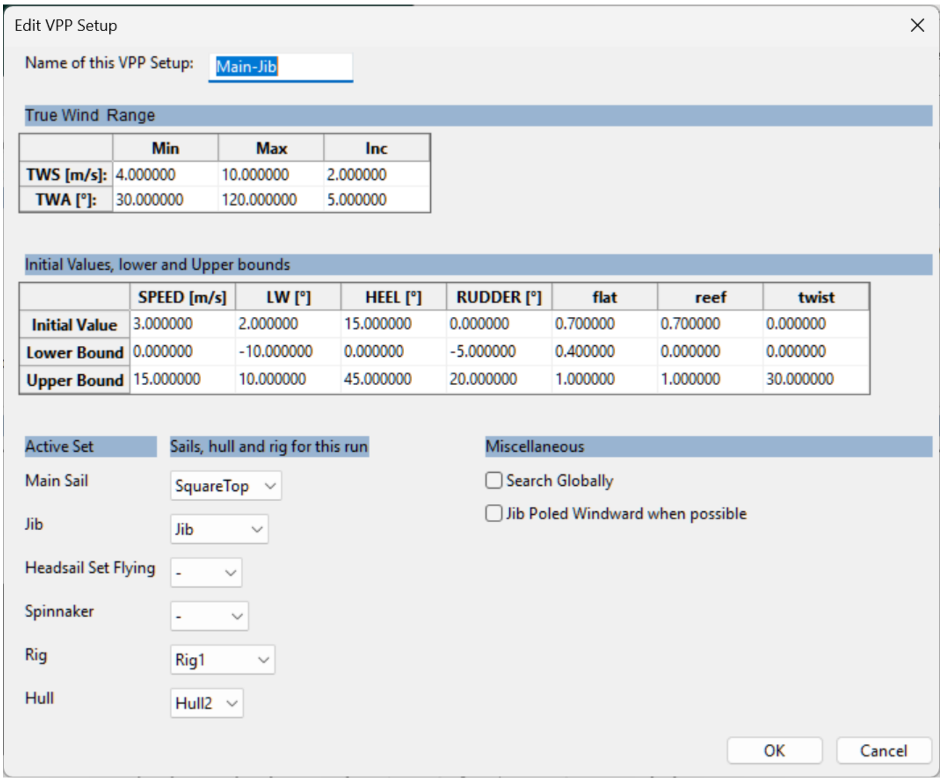


Figure 7: The "Edit VPP Setup" dialog

Here we see two tables. The first defines the true wind speeds TWS and true wind angles TWA for which the performance is predicted. Currently the yacht speed is predicted for wind velocity of TWS=4 m/s, 6 m/s, 8 m/s and 10 m/s and the true wind angle TWA starts at 30° and ends at 120° in steps of 5°.

The next table shows initial values and bounds for the calculation. Making reasonable choices here will increase the accuracy of the performance prediction. CVPP employs an iterative method to calculate equilibrium of all flow forces and find the optimum trim of the sails. As common for iterative procedures choosing smart initial guesses will help the iterative procedure to converge and find a stable solution. Defining proper lower and upper bounds of the sailing states may also help to find reasonable results. If doing wrong here the iterative procedure may come up with strange results.

To the lower left of the dialog you choose the actual sails set for this performance prediction. You have to choose one mainsail, one of the headsails (jib, headsail set flying or a spinnaker), one rig and one hull.

To the right of this you can choose to use a pole for sheeting the jib to windward on deep downwind courses. This has only effects if the headsail is a jib.

There is an option to have CPP use a global optimization scheme. This prolongs the runtime significantly. In most cases global optimization is dispensable for conventional yachts. There are some cases where global optimization gives better results, however it is risky to use global optimization if you do not choose reasonable upper and lower bounds of the free variables, since the global optimizer will investigate the entire optimization set (the complete bandwidth of the free variables given by their upper and lower bounds.

3.5 Comparison of different setups

Let us study the impact of crew weight on the performance. Clearly, a high crew weight will increase the weight as well as the righting moment, compared to a small crew with only minimum number of crew members.

In the object store you find two different hulls, Hull1 and Hull2. The hulls are actually identical, however while Hull1 is defined with a crew of (about 6 sailors weighting) 450 kg and a buoyancy of 5.2 m³, Hull2 has a crew of only 150 kg and a respectively smaller buoyancy.

What do we expect: For sure, on upwind courses the additional crew will increase righting moment and the performance of the boat. However, in lighter wind and on deeper courses, cases where a high righting moment is not really needed, the additional weight of a large crew will harm the performance. Let us quantify this.

Choose “Main-Jib as the VPP setup in the “Velocity Polar” tab. Run the VPP and press the button “Move to buffer”. Double click on the “Main-Jib” object in the VPPsetup category of the object store and change the hull from Hull1 to Hull2. Re-run the VPP. Now check the checkbox “Include buffer” and press the “Plot Polar” button. Your velocity polar should look like this:

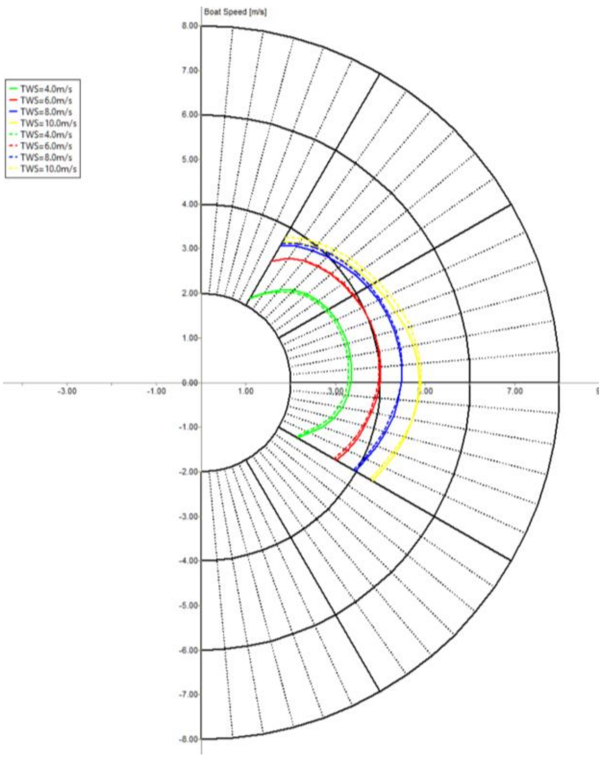
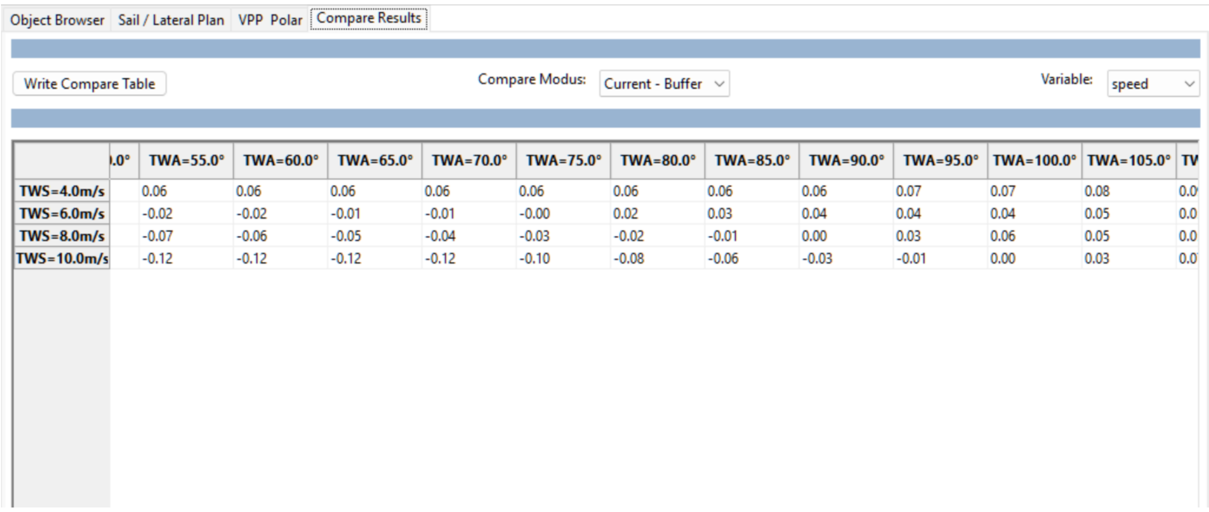


Figure 8;: Comparing two velocity polars

If you look thoroughly, you will detect that we got a result as expected: Remember, that the first calculation, shown as dashed lines, is the boat speed with the high crew weight, while the solid lines show results for the reduced crew weight. We see that at wind speed of 4 m/s the boat with large crew weight is generally slower, while at higher wind speed the additional crew weight increases velocity on the upwind course. However, at deep courses TWA>90° the additional crew weight reduced velocity again due to the additional buoyancy.

However, the differences are hard to detect and we can do better here.

Activate the “Compare Results” by pressing the respective tab on the top of the right panel. Here you can decide, which variable you want to compare, in most cases this will be the boat speed. Set the “Compare Modus” drop down list to “Current – Buffer” in order to show the speed gains of the current calculation, the last one with the reduced crew weight and buoyancy with the results we have shifted to the buffer, the results for the higher crew weight. Press write compare table.



	).0°	TWA=55.0°	TWA=60.0°	TWA=65.0°	TWA=70.0°	TWA=75.0°	TWA=80.0°	TWA=85.0°	TWA=90.0°	TWA=95.0°	TWA=100.0°	TWA=105.0°	TV
TWS=4.0m/s		0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.08	0.0
TWS=6.0m/s		-0.02	-0.02	-0.01	-0.01	-0.00	0.02	0.03	0.04	0.04	0.04	0.05	0.0
TWS=8.0m/s		-0.07	-0.06	-0.05	-0.04	-0.03	-0.02	-0.01	0.00	0.03	0.06	0.05	0.0
TWS=10.0m/s		-0.12	-0.12	-0.12	-0.12	-0.10	-0.08	-0.06	-0.03	-0.01	0.00	0.03	0.0

Figure 9: Comparing different VPP runs

The table contains speed differences, typically a few hundreds of a m/s. We see negative values (speed losses for the light boat with small crew weight) on upwind courses up to TWA < 90° and positive values above.

BTW: a speed difference of 0.05 m/s: is that a lot? Definitely. Assume you are on a club race with an upwind tack of 1.5 nautical miles, taking about 20 min. This will give you an advantage of 60 m at the windward mark – your competitors will have trouble to read the name of your boat on her transom.

You are free to perform any possible comparison. You can compare different sails, rig types, hulls and so. Just add/edit respective objects in the object tree. Do not forget to choose these objects in the respective VPP setup.

BEFORE YOU LEAVE:

Do not forget to save your changes to the object store. For this purpose, use the file menu and choose “Save Entire Tree as JSON”.

4 VPP background

This chapter provides some information about some internals of *CVPP*. Do not expect deep insights into ship or yacht hydrodynamics or wing or sail aerodynamics. For those interested, classical text books are available in large numbers.

A VPP usually consists of three components:

- A hydrodynamic model: an algorithm to predict the flow forces and moments acting on a hull moving steady state with some hydrodynamic *state variables:* speed, leeway angle, heel angle and rudder angle.
- An aerodynamic model: an algorithm to predict the aerodynamic flow forces acting on the rig with sails, set according to some aerodynamic state variables: apparent wind speed and angle as well as flattening, reefing and twisting of the sails.
- A solution algorithm, predicting the set of hydrodynamic and aerodynamic state variables for which all the forces and moments acting on the yachts are in equilibrium and the boat speed achieves a maximum.

For the hydrodynamic model, a regression of the *Delft Systematical Yacht Hull Series DSYHS* is used. This model has been published by the University of Delft, mostly under the responsibility of *Lex Keuning*, a researcher at the university to whom the world of yacht engineers owes a great deal.

The aerodynamic model goes back to *G.S. Hazen*s work in the 70th of the last century. A quite modern variant of this method is used by the *Offshore Racing Congress* for their VPP-based rating system. Thanks to their excellent documentation, the ORC method 2024 has been implemented as the aerodynamic model of *CVPP*.

CVPP is a method with five degrees of freedom (5DOF-VPP), meaning that the equilibrium of forces and moments is taken into account for longitudinal and transverse forces as well as moments around the three axes of the yacht, the heel, pitch and yaw axes. For the remaining vertical force, it is assumed that the hydrodynamic and hydrostatic forces perpendicular to the water surface are in equilibrium with the weight of the boat. This assumption comes from the method of carrying out towing tank tests at the Delft university: while longitudinal and transverse forces are captive and measured, the yacht model is free to move in vertical direction. This is the most common method to do towing tank tests.

Having five equations to solve for equilibrium (5DOF) and 9 aerodynamic and hydrodynamic state variables, we are forced and happy about to base our solution algorithm on optimization. The general solution algorithm employed by *CVPP* is based on *constraint optimization*: searching for an optimum set of state variables, which maximizes the boat speed, while satisfying some nonlinear constraints, basically the equilibrium of the flow forces.

In the following chapters some user information about these three building blocks of *CVPP* is presented. It may help to make proper use of the methods, while any theoretical knowledge about the methods is restricted to a minimum and left to respective publications.

4.1 The DSYHS regression

The DSYHS is a series of models, being investigated in the towing tank of the University of Delft, using models of a size of about 2.5 m (which is quite small). In total, an amount of more than 50 yachts have been tested in the towing tank in different appendage configurations. The

DSYHS developed over years. Older hulls are quite conservative in terms of the shape, while later models feature some modern particulars.

The validity of the regression of the towing tank test results may be questionable for late yacht design trends, for example ultra-light yachts with beamy sterns and chines along freeboard, however it is the best we have, if we want to avoid doing tank tests, CFD investigations or using advanced regression methods based on some integral values derived from line drawings (the method the ORC used for their hydrodynamic model).

The DSYHS regression decomposes the resistance of the yacht according to the Froud method: upright hull and appendage (keel and rudder) resistance calculates from frictional and residual resistance. For heeled states, some corrections of frictional and residual resistance of the hull can be estimated as well as a correction of the keel residual resistance. When generating side force, an additional induced resistance is calculated based on the effective draft of the yacht, the latter one described with regression formulae the same way the other resistance components are predicted by regressions.

For the regression formulas predicting reliable results, it is quite important to take into account the parameter limitations. In particular, the method is restricted to Froud-numbers below 0.7. Heel and leeway angles should be within reasonable bounds (heel < 35°, leeway < 10°).

The DSYHS uses only fin keels. Bulbs commonly used on modern yachts have to be taken into account by their volume including its vertical center, wetted surface and lateral area by smearing the bulb dimensions onto a keel of fin shape.

The hull is described using the following parameters:

Parameter	Symbol	Unit	Comment
Buoyancy of the canoe body (hull)	Vc	m³	in sailing condition (full crew and equippment
Draft of canoe body	Tc	m³	dito
Length of Waterline	Lwl	m	
Beam of Waterline	Bwl	m	
Wetted surface area in upright condition at rest	Sc	m²	
Wetted main sectional area	Ax	m²	largest section, regardless where it is
Water plane area	Aw	m²	
Longitudinal center of buoyancy with respect to origin	LCB	m	remember: origin at gooseneck
Longitudinal center of flotation with respect to origin	LCF	m	projection on waterline
Longitudinal Metacentric height	GMl	m	guess: 2* Lwl
Longitudinal position of forward perpendicular	xFPP	m	distance stem/waterplane intersection to origin
Length reduction factor	Lrefratio		default value: 0.7

In addition, some of the main particulars, Lwl, Bwl, Tc, Ax and Sc, can be defined depending on the heel angle. This is optional. If the data is available, this may increase accuracy. An estimate function is available to guess these values, derived from only a few hull forms. If these values cannot be predicted reliably, do not use tabulated heeled dimensions.

Keel and rudder are described with the following geometric parameters:

Parameter	Symbol	Unit	Comment
Keel Mean profile length	ck	m	Take average between tip and root profile length
Keel mean blade draft	bk	m	from hull lower bound to maximum draft
Profile Thickness ratio	TCRk	-	good guess: 0.12
Keel envelope taper ratio	TRk	-	tip profile length over root profile length
Keel lateral projected area	Ak	m²	including bulb
Keel wetted surface area	Sk	m²	including bulb
Keel volume	Vk	m³	including bulb
Keel rake angle	Lambda_k	°	rake of 1/4 profile length line, best would be 0
Vertical center of Keel buoyancy	Zcbk	m	including bulb
Longitudinal center of effort	LCE_k	m	take 1/4 profile length line at the middle of total draft
Vertical center of effort	VCE_k	m	50% of draft including bulb

Use respective values for the rudder.

In addition to these values some hydrostatic stability parameters have to be defined:

A table describes the righting arm of hull and appendages depending on heeling angle.

- Heel [°] = table of righting arm RA [m].

The righting arm can be estimated from Lwl, Bwl and Aw, if the vertical center of gravity VCG is known. For many modern C/R yachts, VCE=0m is a reasonable guess.

RA can then be guessed by: ### to be done ###

In addition, some crew righting arm parameters can be set if the crew adds to the righting moment:

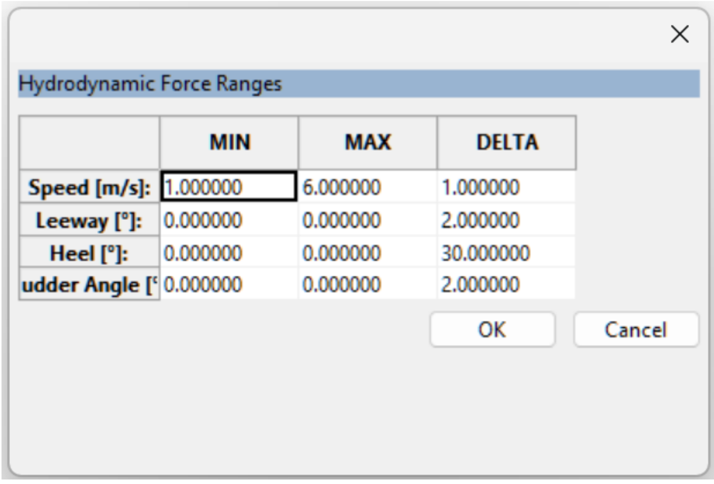
- Crew Weight (mCrew [kg]) is understood to be a movable part of the total weight, given by the total buoyancy. If you add crew weight, do not forget to adapt canoe body buoyancy accordingly.
- Maximum crew arm (yCrewMax [m]), usually half the beam of the boat. It is assumed that the crew switches its position linearly from centerline to the maximum crew arm while the yacht heels from 0° to 7°.
- A maximum righting moment can be defined (Mxr_max[Nm]). It is set to a very high number for a keel yacht. However, if you are investigating a dinghy, which is sailed upright only, set a constraint on the heeling angle to 0° and a maximum righting moment to the moment the sailor can generate when hiking. This will cause the solution algorithm to avoid heeling the boat and depower the sail such that this maximum righting moment is not exceeded.

The Munk moment is a yawing moment due to asymmetries of the hull flow under leeway and or heel. The option to take the Munk moment into account, is currently disabled.

4.1.1 Generating tables of hydrodynamic forces

If you are only interested in hydrodynamic forces, CVPP allows you to generate tables of the hydrodynamic forces acting on the yacht. Consequently, it enables you to do a very fast resistance prediction for other purposes than velocity prediction, e.g. calculation of a propeller.To this end, load a respective JSON file, for example D34, json, go to the “VPP Polar” tab at the right panel, select a VPP setup (to choose a particular hull) and activate the “Calc

Hydro Forces” button. The following dialog will ask you to define a range of the state variables to predict flow forces for:



The result will be given as tabulated data. You can copy it from here to Excel © in order to do further calculations or show the results via respective diagrams.

4.1.2 Further reading

If you want to know more:

J.A. Keuning and B. Verwerft (2009): A new method for the prediction of the side force on keel and rudder of a sailing yacht based on the results of the Delft Systematic Yacht Hull Series, TU Delft Report 1613-P

J.A.Keuning and M.Katgert (2010): The influence of heel on the bare hull Resistance of a sailing yacht, TU Delft Report 1684-P

J.A. Keuning and U.B. Sonnenberg (1998): Approximation of the Hydrodynamic Forces on a Sailing Yacht based on the 'Deift Systematic Yacht Hull Series', TU Delft Report 1175-P, see also: 15th International Symposium on "Yacht Design and Yacht Construction ". Amsterdam, 16 November 1998, The Netherlands.ISBN 90 370 01 71 – 8

J.A. Keuning and M.Katgert (2008):A BARE HULL RESISTANCE PREDICTION METHOD DERIVED FROM THE RESULTS OF THE DELFT SYSTEMATIC YACHT HULL SERIES EXTENDED TO HIGHER SPEEDS, InnovSail 2008

4.2 Aerodynamic coefficients and the Hazen sail force model

CVPP implements the sail force model of the ORC VPP 2024. It is based on diagrams of the lift- and drag-coefficient of individual sails. Individual sails are combined to a so-called aggregate sail, the sail-set by building weighted sums of the coefficients of individual sails. A detailed procedure is employed to predict an effective span, which is used to calculate induced drag of the sail set. *CVPP* allows only to set two sails. The original method assumes that any sail, which is set, contributes to lift and drag, however my personal experience is, that a on a conventional yacht, ajib, set together with a spinnaker does not contribute to the driving force. It may even harm the performance of the spinnaker. To avoid hassles here, *CVPP* only allows to set one mainsail together with either a jib or a spinnaker or a headsail set flying.

CVPP knows three types of headsails: a jib, set on a stay, used for upwind sailing, the spinnakers, either symmetric or asymmetric, the latter once either set on the centerline or on a pole and a headsail set flying (HSF). HSF is not set on a stay and usually has a mid-width larger than 50% of the foot but less than 85% (if this limitation is exceeded, it is a gennaker). A *code-0* falls under this category, but also headsails for deeper courses than the *code-0,* as long as they are set flying and their mid-width does not exceed 85% of the foot.

The area of these sails is predicted from girth measurements, the same way the ORC does this. It is inspired by the way, sailmakers are measuring sail size at their loft: folding leech and luff and measuring the stretched distance of the two fold points at the leech and luff.

Depowering of the sail-set is done with the help of three parameters: flat, reef and twist. Utilizing the flat factor depicts any linear reduction of the aggregate lift coefficient. The VPP does not distinguish whether this is done by flattening the sail by reducing the profile depth, or by decreasing the angle attack of the sail with respect to the wind, usually by easing the traveler of the yacht. *CVPPs* twist parameter is a linear reduction of the angle of attack with height, while maintaining constant lift by sheeting the traveler in. This has two consequences: the vertical center of effort of the sail is lowered as well as the effective span, generating an increase of induced resistance. The investigation behind this has been developed at the University of Applied Sciences Kiel with the help of a vortex lattice code. It is not part of the ORC sail force model, which uses a different approach. The advantage of *CVPP's* method is, that twist is an independent parameter which can be optimize independently of flattening of the sail.

Depowering of the sail forces by reducing sail area is done with the help of a *reef* factor. *reef* works differently for a main/jib sail set and the other sail sets. For sail sets with spinnaker or HSF, *reef* is a reduction of the luff with a reduction of sail area depending on reef squared. This is only correct for triangular sails and only acceptable for yachts not on an upwind tack. For the main/jib sail set *reef* depicts a reduction of the luff of the sail, where the envelope of the reefed sail remains constant above the reef line. This allows to take details of the sail envelope into account, e.g. pin-head versus square head main sail or heavily roached jibs.

In either case, *reef*, *flat* and *twist* are continuous and differentiable variables – thank goodness, as this facilitates the implementation of an optimization process. In fact, any sail wardrobe is limited in the number of sails and also reefing of a main sail is usually restricted to the reef lines at the sail. The idea behind this is, that the ORC measurement system only measures the largest sails and leaves it to (the hopefully well-filled wallet of) the yacht owner, to purchase headsails which cover the optimal reef factors depending on wind conditions as good as possible.

If we want to avoid this, we need to model a larger number of headsails, freeze the reef factor (set lower as well as upper bound to 1) and calculate a velocity prediction for any of the modelled sail combinations.

When defining a sail, there are a couple of parameters which take details into account:

- Low tech material for the sail: if we are not using laminate sails, the ORC VPP and so *CVPP* take that into account by reducing the lift coefficients while the drag coefficient remains constant.
- Adjustability: Rigs with backstay, checkstay and maybe multiple aft stays allow better control of the sail shape than rigs without. The logic of *CVPP* (and the ORC) is, that a rig without the mentioned trim stays has to be trimmed to give flat sails (tight forestay, mast bend controlled by the aft stay only). If we do have the trim stays, we are able to

ease the forestay tension to have a deeper foresail profile and to tighten a check stay to have a deeper main sail profile. Consequently, the lift coefficients for sails on rigs having the extra trim stays are higher, this being advantageous in light wind condition. *CVPP* allows three grades of *Adjustability: low, medium and high.* It is left to the user to decide if his yacht used a rig with fixed rig with sweep back spreaders or a top-of-the-notch rig with the latest trimming facilities – or something in between.

- *CVPP* also adapts ORC's method to rate sail set where a single jib is used which can be reefed using a roller furling system. These head sails usually are taken into account with a lower lift coefficient. Authors comment: do not use them, they are ugly.

The rig: The following parameters are used to define the rig:

Element	Symbol	Unit	Comment
Stay Wire Diameter	DW	m	
Boom height	BD	m	
Distance of Sheerline to forestay hound	IG	m	CVPP assumes a straight horizontal sheerline from stem to stern
Mainsail Foot above Sheerline	BAS	m	
Distance Jib Tack to Mast	J	m	leading edge of the mast
Height of the sheerline above water level at rest	HD	m	the deck height
Distance spinnaker or HSF tack to mast	TPS	m	Here you take into account a fixed or an extendable bowsprit
Beam over all	BOA	m	>
Length over all	LOA	m	
Mast transverse dimension	MW	m	use an average for tapered masts
Mast longitudinal dimension	ML	m	dito
Mast height	MH	m	from deck

The values: DW, BOA, LOA, MW, ML, MH and N_SPREADERS are just used for prediction of windage element forces (wind resistance). They do not have any effect on the sails lift and drag production. Take care of the mast height: MH ≥P+BAS (main sail parameters).

CVPP currently leaves it to the responsibility of the user to design a rig and sails fitting together. There are only minor input checks. If you design a rig with a mast height half as large as the mainsail luff, *CVPP* will swallow that without getting hiccups. To implement proper and failsafe input validation is a future task – and it is not the job that a VPP programmer longs for.

Lateral balance: the ORC sail force method knows formulas for the calculation of the vertical center of effort VCE. It is used to calculate the heeling and pitching moments due to sail forces. However, any means to calculate a yawing moment is not given. To circumvent this and for the time being, the longitudinal center of effort LCE of the sail set is fixed to zero, saying, that the longitudinal center of effort is situated at the longitudinal position of the gooseneck of the rig. This gives reasonable results for the rudder angle.

4.2.1 Prediction of aerodynamic forces

As for the hydrodynamic forces you can calculate aerodynamic forces unrelated to a velocity prediction. To do so, choose a VPP setup after loading a JSON file of the project, e.g. the D34.json. Go to the "VPP Polar" tab at the right panel, select a VPP setup (to choose a particular range of wind speeds and wind angles) and activate the "Calc Aero Forces" button. *CVPP* will generate a table with the aerodynamic forces for the given range of true wind speed and true wind angle. For boat speed, heel and leeway angle the initial values of the VPP setup are chosen.

4.2.2 Further readings

HAZEN, G.S., 'A Model of Sail Aerodynamics for Diverse Rig Types', *Proc. New England Yacht Symposium, New London, Connecticut/USA,* 1980.

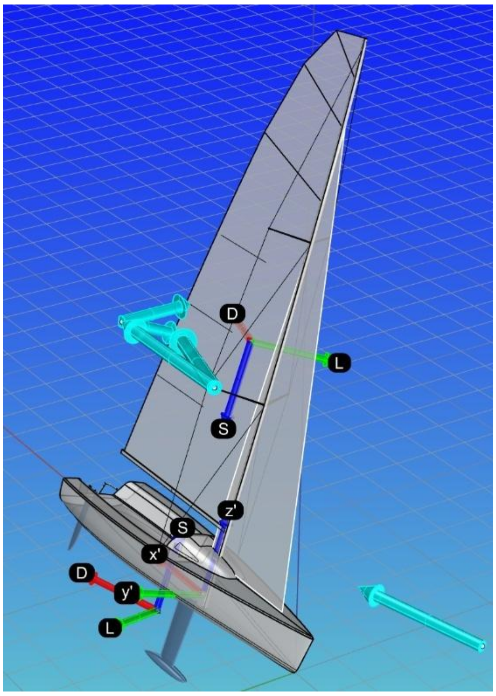
Offshore Racing Congress, various authors, ‘ORC VPP Documentation 2024’, London, UK, 2024

5 The solution procedure

The solution procedure is based on the mathematical principle of nonlinear constraint optimization.

Prerequisite is the calculation of all flow forces acting on the yacht. This is done using the above-described methods. Since these methods usually calculate lift, drag and spanwise forces, some coordinate transformation is necessary to transfer the aerodynamic as well as hydrodynamic lift and drag data to a common, boat-fixed coordinate system, called x’,y’,z’ coordinate system.

The coordinate systems for the flow forces are called DLS-coordinate systems (for drag-lift-span). Obviously, they differ for aero- and hydrodynamic forces. For the aerodynamic forces, it is common practice to separate the apparent wind into a component parallel and transverse to the yacht center line and calculate an effective apparent wind angle and speed which only takes the component of the transverse wind perpendicular to the mast-centerline plane into account. This is a simple method to predict aerodynamic forces for heeled yacht states if only wind tunnel test results with models tested in upright condition are available.



For the hydrodynamic forces this approach is not necessary, since tank test results are commonly obtained for the upright towed yacht as well as for the heeled yacht. Consequently, the leeway angle is not corrected as it is the case with the apparent wind.

With a guess of the aero- and hydrodynamic state variables, the flow forces can be calculated and summarized in the boat-fixed global coordinate system, and – unless we are geniuses at estimating boat performance data – these forces and moments will be different from 0. The VPP solver has the task of calculating the state variables for which the flow forces are in equilibrium. More than that, the solver has to find that set of state variables for which the boat speed achieves a maximum.

Many VPPs separate the algorithms for equilibrium finding and optimization and lots of brain went into the effort to do this smart and effective. *CVPP* uses an approach to predict an optimum set of the state variables and tries to find an equilibrium of flow forces as a side effect.

Non-linear constraint optimization is the magic word behind this approach. These algorithms search an optimum of an objective function with a free variable set, the objective function depends on. Beside this, some constraints are satisfied, in our case the condition, that all flow forces and moments sum up to zero.

In our case the objective function is the speed of the boat in the direction of the course. So, we demand:

$$u_B \cdot \cos(\lambda) = \max$$

where u_B is the boat speed and λ the leeway angle. The free variable set are our state variables, in particular *reef*, *flat* and *twist*¸ leeway, heel and rudder angles, but also boat speed and apparent wind angle and speed.

Some remarks on the optimization algorithm:

> The optimization method *CVPP* uses is called COBYLA. COBYLA (Constrained Optimization BY Linear Approximations) is a derivative-free optimization algorithm that handles nonlinear constraints. It approximates the objective and constraint functions using linear models built from function evaluations and iteratively updates a trust region to search for the minimum of $-u_B \cdot \cos(\lambda)$.
>
> Other optimization methods have been investigated, in particular interior point methods. They are generally faster than COBYLA, but depend on Jacobians and a Hesse matrix. Both can be approximated using finite differences, however that is computational expensive and hard to program failsafe.
>
> COBYLA finds a local optimum. Do we need global optimization? If our objective function and the variable set are convex, a local optimum is a global one as well. Test calculations gave the result, that this is the case for the vast majority of investigated hulls, sails and so on. For cases, where the hull resistance increases with speed and decrease again at higher speeds, the objective function is not convex. Physically this may happen for ultralight boats, foiling boats and the like. More important, a non-convex objective function may arise from the regression methods, in particular if the parameter space of the regression formulas is left.
>
> That is the reason for employing upper and lower bounds for the variable set. They should carefully be chosen. In particular the Froud number is limited to $Fn<0.75$. Also heeling, leeway and rudder angles should be limited. *CVPP* will try it's upmost to predict boat speed for unconventional variable sets, However, if your calculations show results of boat speeds of 30 kts of your 9 m Colin-Archer-like design with a heeling angle of 120°, be suspicious.

CVPP will be enhanced in the future. More advanced aerodynamic methods will be implemented, certainly increasing the number of free optimization variables. COBYLA is limited with respect to its performance for large number of optimization variables, so the optimization procedure may change in the future.

6 File formats

CVPP makes use of two different file formats: CSV-files and JSON files.

Velocity polar results are stored on demand as a CSV-file, ready to be imported into a spreadsheet program. CSV-files can be saved and loaded again so you can save results for reimporting them later on. Moreover. it is quite easy to format velocity polars from other VPPs as CSV-file, in particular you can easily generate respective tables from the ORC measurement certificates. This has been implemented to easily compare ORC-VPP data with those of *CVPP*.

The second file format used by CVPP is the JSON format (Java Script Object Notation). JSON is a human readable file format which can be edited using a conventional text editor. There is no need within *CVPP* to use a text editor, but if you want to do so anyway, do not hesitate.

JSON files are based on the principle, that data is represented as objects by unordered key-value pairs, e.g.:

```
{
“Name”: “MyHull1”,
“Lwl”: 123.4                    // unit: m
}
```

The braces {} denote that this is a JSON object. *CVPP* supports comments in the JSON file using the C++-syntax //.

The values of the key-value pairs can be: number, either integer or real, bolean (true, false), a literal (“MyHull1”), null, a list embedded in [ ] and a JSON object (making JSON recursive). The lists can hold any arbitrary number of JSON data of same type, e.g.:

```
“KidNames”: [ “Freja”, “Pauline”, “Julien”]
“AVector”:    [1.0, 1.21, 1.44]
```

JSON lists may without any problem contain complex objects, themselves consisting of key-value-pairs of any JSON data type.

Let us look, how this format is used to define spinnakers:

```
{
    "SPI": [
        {
            "Name": "SS",
            "SFL": 6.0,
            "SHW": 6.0,
            "SLE": 12.0,
            "SLU": 12.0,
            "SPITYPE": "SS",
            "SPL": 4.0
        },
        {
            "Name": "ATOC",
            "SFL": 6.0,
            "SHW": 6.0,
            "SLE": 13.0,
            "SLU": 15.0,
            "SPITYPE": "ATOC",
            "SPL": 4.0
        }
    ]
}
```

The outer braces { and } denote this to be an object. This object holds a single key-value pair, the key being “SPI”. The value is a list, denoted by brackets []. This is the list of spinnakers available in this file. A spinnaker is an object {}, holding a couple of key-value pairs, where the values now are numbers (“SFL”: 6.0) and strings (“Name”: “SS”). Names are arbitrary in *CVPP*, they are just for the user to distinguish his objects. Note the commas, separating objects in the list and key-value pairs in the objects. Two spinnakers are shown in the list, named “SS” and “ATOC”.

This data scheme is used throughout *CVPP* for defining sails, hulls, rigs and so on. For hand written JSON files, you have to stick to it. Remember, even if you have a single spinnaker in your project, this spinnaker has to be an object in a list.

JSON files can be used as single objects, for example a single sail, rig or whatever, or all the objects of your project can be combined in a single file. The example folder contains many individual objects, sails, rigs and so on, but also a complete project, the D34, containing a couple of sails, hulls …

To edit JSON files, use a text editor, that understands the JSON format. Microsofts *Visual Studio Code* is a freeware text editor which is well suited for editing JSON files, but there are many alternatives.

Note that JSON files red be *CVPP* may contain comments (// this is a comment), however if you write JSON files using *CVPP's* JSON save command, the comments are lost.

Kiel, 29.11.2025, K. Graf

Annnex

Future developments

CVPP will be enhanced in the future. It is intended to fix bugs, validate results and add new methods for the prediction of flow forces.

Any hints, comments and proposals are welcome and I am willed to constantly work on the code.

My TODO-List

- Input validation, in particular for the tables
- Hull Assistant, allowing to define a hull with only few parameters (Lwl, Bwl, Vc)
- Sail assistant

- Seekeeping model
- Longitudinal centre of effort for the sail forces
- Lifting Line sail force model
- ORC resistance model if an offset table is available
- …