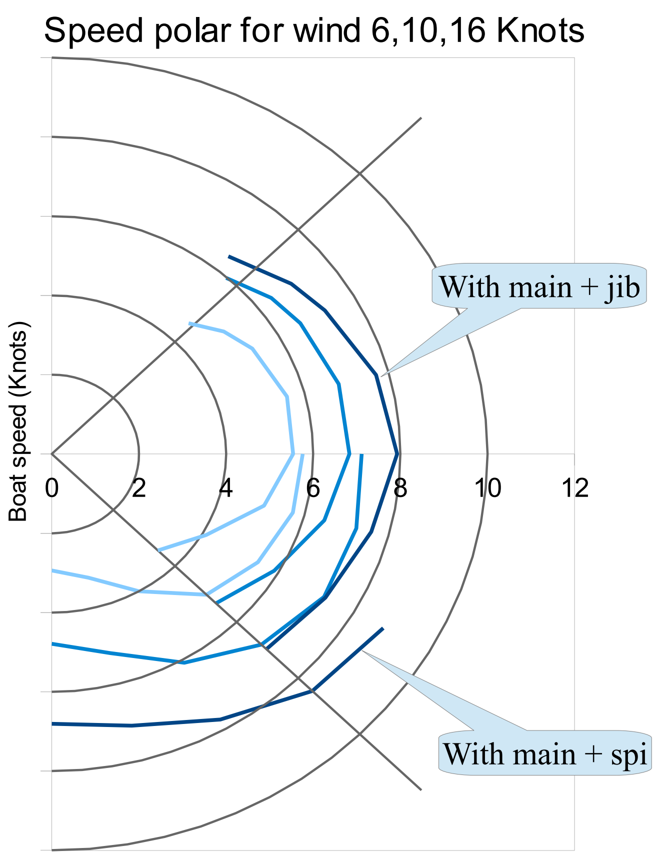
Gene-VPP Sailboat 3.5_User Guide

In this 3.5 version, nothing change for the input data, but new output data are proposed in complement :

A speed prediction table, example :

Upwind on calm water							
Wind (Knts)	**6**	**8**	**10**	**12**	**14**	**16**	**20**
Twa (°)	43,6	42,9	42,0	41,0	40,0	39,1	38,0
Vboat (Knts)	4,55	5,51	5,98	6,22	6,36	6,42	
With Mainsail + Jib (or Genoa)							
Twa (°)							
52	5,01	5,95	6,39	6,63	6,83	6,97	
60	5,31	6,19	6,59	6,84	7,06	7,24	
75	5,59	6,37	6,82	7,15	7,44	7,71	
90	5,54	6,35	6,83	7,24	7,61	7,93	8,43
105	5,04	5,95	6,47	6,87	7,25	7,60	8,16
120	4,09	5,10	5,90	6,44	6,86	7,25	7,93
135	3,44	4,43	5,33	6,04	6,55	6,97	7,75
With Mainsail + Spi (sym or asym)							
90	5,76	6,61	7,11	7,46			
105	5,73	6,63	7,24	7,71	8,05		
120	5,47	6,51	7,22	7,83	8,36	8,78	
135	5,02	6,21	6,81	7,36	7,91	8,46	9,71
150	4,00	5,16	6,08	6,70	7,22	7,74	8,94
165	3,23	4,25	5,20	6,01	6,60	7,10	8,07
180	2,94	3,89	4,79	5,65	6,30	6,81	7,73

A speed polar 3 wind forces (6, 10 , 16 Knots) , example :



Gene-VPP Sailboat 3.5 (Velocity Prediction Program) makes possible the prediction of the boat speed and of the heel angle for 3 typical sailing conditions by wind 4 to 20 Knots :

- Upwind on calm water, with pre set twa in function of wind
- Reaching, with from twa 45° to 135°
- Downwind with spi (symetric or asymetric), with from twa 90° to 180°

The main goal is to provide a helpful tool one can integrate in the design loop to optimise a project at its early stage with regard the performance objectives, able to show and to quantify in terms of boat speed the influence of such or such parameter and so to guide the project towards an optimum. The input consists of a relatively short list of data representative of the hull, the appendages (keel, bulb, rudder), the displacment, the sailplan, the righting moment, the wetted surface. The ouput are the speed curves with wind force for these 3 sailing conditions, as also the heel angles and the drags.

It is a free and open source speadsheet application, developed on a support itself free and widespread (Open Office Calc 4.0.1) : to open and use an ods file, you have to download Open Office or Libre office according to : http://www.openthefile.net/extension/ods

This application can be used stand alone, in complement to any other software used for the project development and providing the necessary data. For the User of « Gene-Hull Sailsboat 3.5» application, a specific process help prepare the set of input data for « Gene-VPP » : once fulfilled, you have then just to copy/paste these data. In the present User Guide, you will find all information necessary to prepare this set of data, whatever their upstream source. In complement, a technical annex is proposed with all the formulations and algorithms involved, for those interested to know the basis of this prediction program. And for any questions or improvement requests, you can contact me.

Jean-François Masset - March 2026 contact : jfcmasset@outlook.fr

Summary presentation

The spreasheet application includes 2 sheets :

- VPP
- Data storage

VPP : includes an User space (input & outputs) followed by an Administrator space (from line 131) where all the computations are carried out. The User space includes 2 sections :

1. Input data

2. Output data
   - 2.1 Upwind on calm water
   - 2.2 Reaching, twa to input betwwen 45° and 135°
   - 2.3 Downwind with spi, twa to input between 90° and 180°
   - 2.4 Figures about boat speed, heel angle, Flat optimum, Righting Moment RM, Drag
   - 2.5 Speed table and polar (new for this 3.5 Version)

Data storage : is the storage space of the input data.

VPP sheet / 1. Input data

The input data can be fulfilled step by step from any sailboat project. The present User guide first address this process.

If you use Gene-Hull Sailboat 3.3 for your early stage project, the table of input data can be prepared within this application, and then you have just to do a copy/special paste towards the Gene-VPP spreadsheet. This approach is also adressed in the present User Guide.

Data to enter are in lines 10 to 18, columns A to O , cells B12 to B68.
Example with boat V1 values (the reference boat of Gene-Hull Sailboat 3.5), 16 other examples are stored in the sheet « Data storage »:

For Gene-VPP, hull body data with loading and at equilibrium upright (put Heel = 0°)							From the Sailplan sheet :							
Lwl (m)	Bwl (m)	Tc (m)	Bmax (m)	Cp hull	LCB hull(%)	Sf (m2)	Main (m2)	Jib (m2)	ZCE (m)	Zdeck (m)	Zmast (m)	Spi (m2)	ZCE spi (m)	Reefing
8,26	2,24	0,39	2,60	0,54	47,34	12,50	23,06	24,04	5,26	0,85	13,23	70,00	6,31	1,00
Keel wing			Keel bulb (if no bulb, put Vol. = 0 and Sw = 0)				Rudder			Displacement and draft at design load			sym0 asym1	Flat mini
Vol. (m3)	Sw (m2)	Chord (m)	Vol. (m3)	Sw (m2)	L (m)	D (m)	Vol. (m3)	Sw (m2)	Chord (m)	Disp. (kg)	Draft (m)		0	0,75
0,09749	2,37	1,15	0,05190	1,30	1,55	0,28	0,01486	0,91	0,40	2973	1,77			
Righting Moment RM (kN.m)				Wetted surface Sw (m2)										
RM0°	RM20°	RM30°		Sw0°	Sw20°	Sw30°								
2,943	12,158	15,144		18,25	17,51	17,08								

Each data is described here after :

The hull body upright (without its appendages), for the sailboat with its design loading :

Lwl (m)	Bwl (m)	Tc (m)	Bmax (m)	Cp hull	LCB hull(%)	Sf (m2)
8,26	2,24	0,39	2,60	0,54	47,34	12,50

Lwl (m) : lenght of waterline

Bwl (m) : beam of waterline

Tc (m) : maximum draft of the hull body

Bmax (m) : beam overall

Cp : prismatic coefficient of the hull body

LCB (%) : longitudinal location of the center of buoyancy of the hull body, counted from the rear point of the waterline and in % of the Lwl

Sf (m2) : floatation area

Keel wing and bulb (if any)

Keel wing			Keel bulb (if no bulb, put Vol. = 0 and Sw = 0)			
Vol. (m3)	Sw (m2)	Chord (m)	Vol. (m3)	Sw (m2)	L (m)	D (m)
0,09749	2,37	1,15	0,05190	1,30	1,55	0,28

Vol.(m3) : volume of the keel wing ; of the bulb

Sw (m3) : wetted surface of the keel wing ; of the bub

Chord (m) : root chord of the keel wing profile (this data is used to compute the Reynolds)

L (m) : Length of the bulb

D (m) : Diameter of the bulb

Rudder

« Rudder » can be either a suspended rudder, a rudder with including the skeg, or twin rudders :

Rudder		
Vol. (m3)	Sw (m2)	Chord (m)
0,01486	0,91	0,40

Vol. (m3) : volume of the « Rudder »

Sw (m2) : wetted surface of the « Rudder »

Chord (m) : root chord of the « Rudder », (this data being used to compute the Reynolds)

Displacement and draft at design load

Displacement and draft at design load	
Disp. (kg)	Draft (m)
2973	1,77

Disp. (kg) : Displacement of the sailboat with its design loading

Draft (m) : Draft of the sailboat for this loading (called **T** in the formulations)

Sailplan

From the Sailplan sheet :							
Main (m2)	Jib (m2)	ZCE (m)	Zdeck (m)	Zmast (m)	Spi (m2)	ZCE spi (m)	Reefing
23,06	24,04	5,26	0,85	13,23	70,00	6,31	1,00
						sym0 asym1	Flat mini
						0	0,75

Main (m2) : Mainsail area

Jib (m2) : Jib area (could be the one of a Genoa or a Code 0)

ZCE (m) : height of the center of effort for this Main + Jib definition / waterplane

Zdeck (m) : height of the deck at foot step / waterplane

Zmast (m) : height of the mast (exactly the top point of the mainsail) / waterplane

Spi (m2) : Spinnaker area **sym0 asym 1** = 0 asymetric spi ; = 1 asymétric spi

ZCE spi (m2) : height of the center of effort of Mainsail+Spi

Reef : coefficient. Reef = 1 >>> above sails area and ZCE are taken unchanged
Reef < 1, for example 0,8 :
>>> sails area are reduced by (0,8) ^2 = 0,64
>>> (ZCE - Zdeck) is lower by 0,8

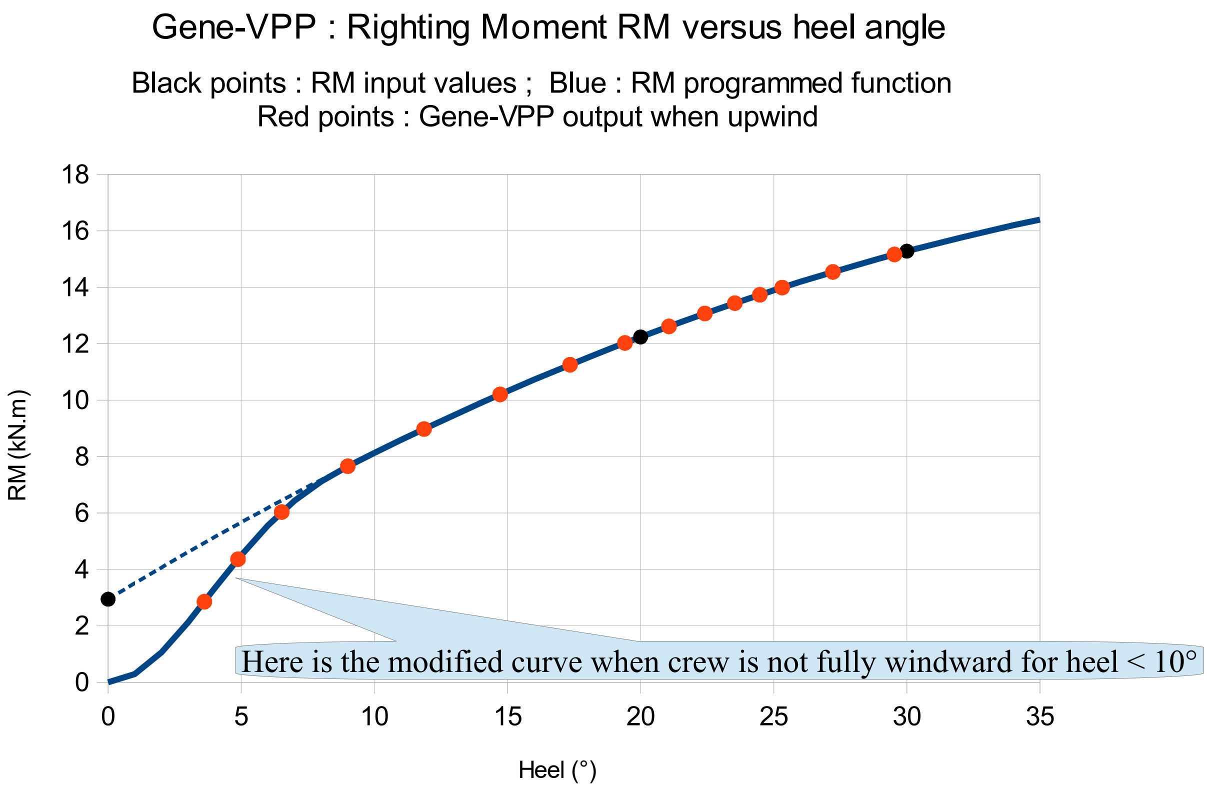
Flat mini : Flat is a coefficient which can numerically « flatten » the camber of the sails through the reduction of the Lift coefficient. This coefficient is automatically optimised in the Upwind conditions only, from 1 by light winds **down to Flat mini** by breeze. Flat mini cannot be lower than 0,5 , meaning sails of very high quality able to be flatten at such : if you have more standard sails but with modern cut, you can moderate this flatness capacity by setting a Flat mini of about 0,6. If you have average standard sails, preferable to set a Flat mini at around 0,75.

Righting Moment RM

Righting Moment RM (kN.m)		
RM0°	RM20°	RM30°
2,943	12,158	15,144

RM0° , RM20°, RM30° (kN.m) : righting moment at heel angle respectively 0°, 20°, 30°

>>> the system automatically compute an RM function based on these values
>>> RM0° can be > 0 when considering a crew sit windward. In that case, the system considers that the crew progressively moves from center to windward when heel evolves from 0° to 10°

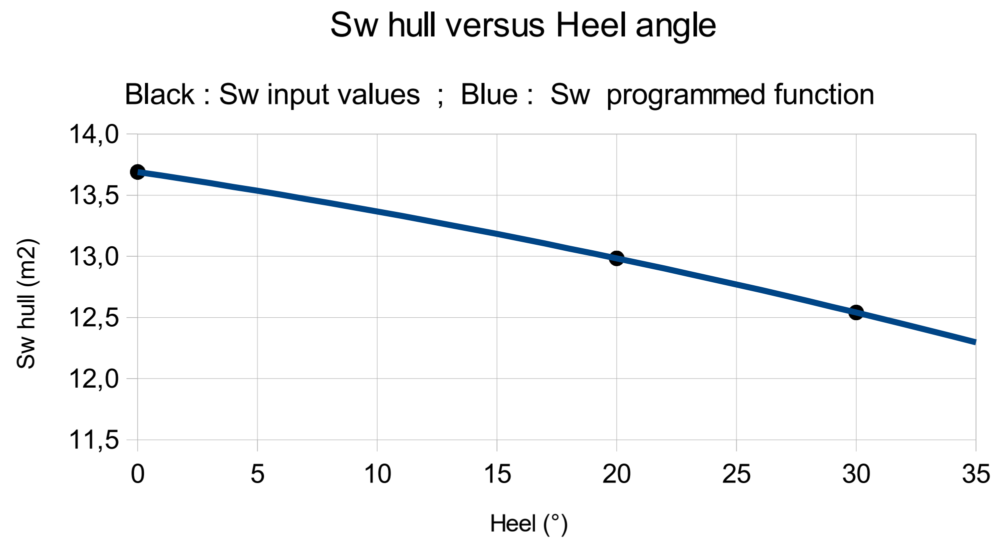


Wetted surface Sw

Wetted surface Sw (m2)		
Sw0°	Sw20°	Sw30°
18,25	17,51	17,08

>>> Sw0° , Sw0°, Sw30° (m2) : total wetted surface (hull body and appendages) at heel angle respectively 0°, 20°, 30°

>>> the system automatically compute the <u>Sw hull body part</u> in function of the heel angle, the Sw of the appendages being not affected by the heel (at first order).



For the User of Gene-Hull Sailboat 3.5 :

The whole set of input data for Gene-VPP is prepared within the sub-section 5.3 of Gene-Hull sheet, lines 282 to 290, columns L to Z.

All the data are automatically (but RM and Sw) gathered in these cells, with 2 remarks :

Remark 1 : For the hull body data

For Gene-VPP, hull body data with loading and at equilibrium upright (put Heel = 0°)						
Lwl (m)	**Bwl (m)**	**Tc (m)**	**Bmax (m)**	**Cp hull**	**LCB hull(%)**	**Sf (m2)**
8,26	**2,24**	**0,39**	**2,60**	**0,54**	**47,34**	**12,50**

>>> to obtain automatically these data, the 5.1 (loading) and 5.2 (hydrostatic equilibrium) should be first set and balanced respectively for the design loading and for heel = 0°.

Remark 2 : The RM and the Sw values should be copy/special paste by the User from the equilibrium at respectively Heel 0°, 20° and 30°.

From these 2 remarks derives **the process to fulfill the set of data for Gene-VPP** , here after describe step by step :

1) To input the desired loading in 5.1 . Example, here a load of 300 kg with its Xg, Yg , Zg :

5.1 Mass spreadsheet with input of a load					
Data to enter : yellow cells	**Mass (kg)**	**Xg (m)**	**Zg (m)**	**Yg (m)**	(in the coordinates of the 2D
Displacement of ref. (kg)	*2672,61*	*3,782*	*-0,078*	*0*	*from the mass spreadsheet*
Load (kg)	**300,00**	**2,00**	**0,85**	**0,00**	Crew at center
			0,85	**1,00**	Crew sit windward
Total >>> Mass (kg)	**2972,61**	**3,602**	**0,015**	**0,000**	**Crew at center**
Disp. (m3)	**2,90011**		**0,015**	**0,101**	**Crew sit windward**

2) To compute the equilibrium in 5.2 **at heel = 20°** , and copy/special paste (number, format) the RM and the Sw values (in the example : **12,158 kN.m** and **17,51 m2**)

Data to enter : yellow cells		Results			
Heel (°)	20	Disp. (m3)	2,90011	/ Disp. (m3)	2,90011
Height (cm)	3,2629	Xc heel (m)	3,602	/ Xg (m)	3,602
Trim (°)	0,170	Yc heel (m)	-0,327	Yg heel (m)	0,090
		Zc heel (m)	-0,196	> GZ (m)	0,417
		Sw heel(m2)	17,51	RM (kN.m)	12,158

3) To compute the equilibrium in 5.2 **at heel = 30°** , and copy/special paste (number, format) the RM and the Sw values (in the example : **15,144 kN.m** and **17,08 m2**)

Data to enter : yellow cells		Results			
Heel (°)	30	Disp. (m3)	2,90011	/ Disp. (m3)	2,90011
Height (cm)	9,6824	Xc heel (m)	3,602	/ Xg (m)	3,602
Trim (°)	-0,253	Yc heel (m)	-0,440	Yg heel (m)	0,080
		Zc heel (m)	-0,198	> GZ (m)	0,519
		Sw heel(m2)	17,08	RM (kN.m)	15,144

4) To compute the equilibrium in 5.2 **at heel = 0°** , and copy/special paste (number, format) the RM and the Sw values (in the example : **2,943 kN.m** and **18,25 m2**)

Data to enter : yellow cells		Results				Specific results			
Heel (°)	0	Disp. (m3)	2,90012	/ Disp. (m3)	2,90011	Relevant only when heel = 0°		DLR	147
Height (cm)	-2,1799	Xc heel (m)	3,602	/ Xg (m)	3,602	Lwl (m)	8,26	Z fore (cm)	1,7
Trim (°)	0,520	Yc heel (m)	0,000	Yg heel (m)	0,101	Bwl (m)	2,24	Z aft (cm)	-5,6
		Zc heel (m)	-0,190	> GZ (m)	0,101	Tc (m)	0,39	Trim (°)	0,52
		Sw heel(m2)	18,25	RM (kN.m)	2,943	Cp Hull	0,537	LCB Hull (%)	47,34

, **and then the blue values said « relevant only when heel = 0° » are also automatically recopied in the corresponding cells of input data for Gene-VPP / hull data part.**

>>> The set of data (as showed here below) is then fully fulfilled and **ready to be copy/special paste (text, number, format)** towards the Gene-VPP application.

For Gene-VPP, hull body data with loading and at equilibrium upright (put Heel = 0°)							From the Sailplan sheet :							
Lwl (m)	Bwl (m)	Tc (m)	Bmax (m)	Cp hull	LCB hull(%)	Sf (m2)	Main (m2)	Jib (m2)	ZCE (m)	Zdeck (m)	Zmast (m)	Spi (m2)	ZCE spi (m)	Reefing
8,26	2,24	0,39	2,60	0,54	47,34	12,50	23,06	24,04	5,26	0,85	13,23	70,00	6,31	1,00
Keel wing			Keel bulb (if no bulb, put Vol. = 0 and Sw = 0)				Rudder			Displacement and draft at design load			sym0 asym1	Flat mini
Vol. (m3)	Sw (m2)	Chord (m)	Vol. (m3)	Sw (m2)	L (m)	D (m)	Vol. (m3)	Sw (m2)	Chord (m)	Disp. (kg)	Draft (m)		0	0,75
0,09749	2,37	1,15	0,05190	1,30	1,55	0,28	0,01486	0,91	0,40	2973	1,77			
Righting Moment RM (kN.m)				Wetted surface Sw (m2)										
RM0°	RM20°	RM30°		Sw0°	Sw20°	Sw30°								
2,943	12,158	15,144		18,25	17,51	17,08								

To note that in case the 5.2 sub-section is not set at Heel = 0 with its equilibrium for this final step, the cells for the hull body data will show this warning message to remind you to set Heel = 0

For SA-VPP, hull body data with loading and at equilibrium upright (Heel = 0°)						
Lwl (m)	Bwl (m)	Tc (m)	Bmax (m)	Cp (%)	LCB (%)	Sf (m2)
Put Heel 0	Put Heel 0	Put Heel 0	2,60	Put Heel 0	Put Heel 0	Put Heel 0

The warnings to input in the VPP sheet (below the table of data)

lot of heel (°)	22,00	max aws	30,00	Convergence issue	0,2
overheel (°)	25,00	(Knots)			1

The User can input other values than the one proposed in standard for the heel and for the maximum of the apparent wind speed aws. For the convergence issue, it is recommended to keep unchanged the thresholds. To note that then the output **results for Heel > overheel (or 30°) if any are not showed**, even if the computation converges.

VPP sheet / 2. Ouput data

From line 21 : Gene-VPP gives the speed predictions for 3 cases supposed to be representative of the sailboat typical sailing, in order to help optimize the sailboat design through further iterations :

2.1 Upwind on calm water,
2.2 Reaching, twa to enter : from 45° to 135°
2.3 Downwind with spi, twa to enter : from 90° to 180°
2.4 Figures about Boat speed, Heel angle, Flat optimum, Righting Moment, Drag
2.5 Speed table and polar (new for this 3.5 Version)

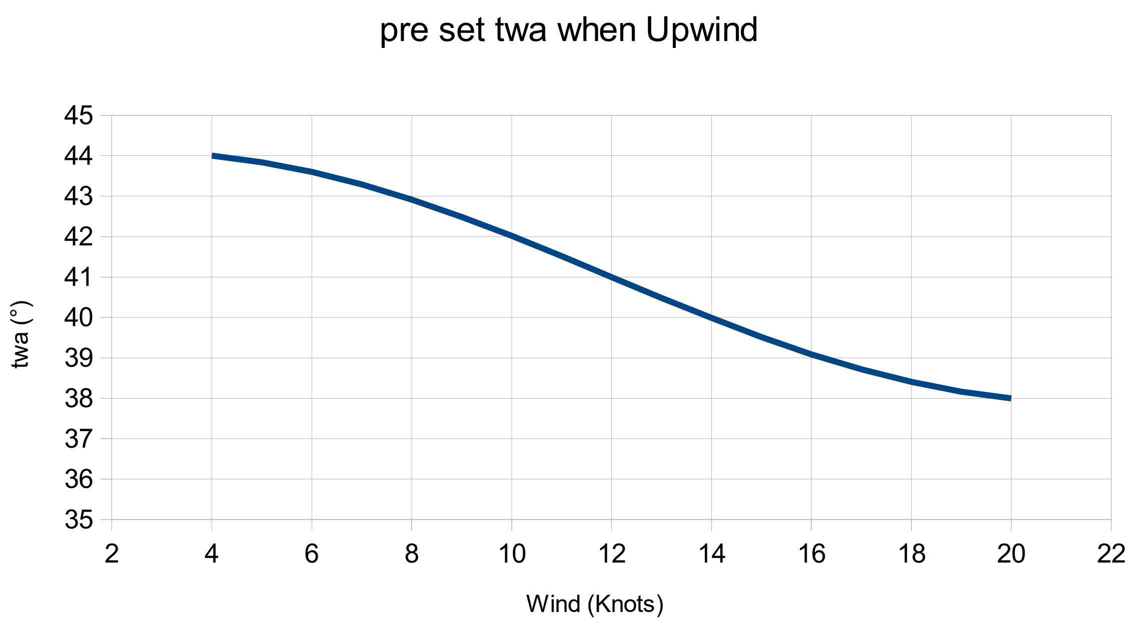
2.1 Upwind on calm water

Output data are in lines 21 to 43 , columns A to AD , including :

Wind		Ship Heel		Ship Speed	VMG		Pdyn :
Vw10	**twa**	**Phi**	Vw	**Vb**	**VMG**	Vb	½ Rho Vb^2
(Knots)	(°)	(°)	(Knots)	(Knots)	(Knots)	(m/s)	

Vw10 : wind force at 10 m above the water, from 4 to 20 Knots, step 1
twa : pre set true wind angle which is or close to the optimum one for the considered wind speed, from 44° (Wind 4 knots) to 38° (Wind 20 Knots).

Vw10 (Knots)	**twa** (°)
4	44,0
5	43,8
6	43,6
7	43,3
8	42,9
9	42,5
10	42,0
11	41,5
12	41,0
13	40,5
14	40,0
15	39,5
16	39,1
17	38,7
18	38,4
19	38,2
20	38,0



If you does not agree with this pre-set, or you want to test with other values, you can change one or all of these twa values.
Phi : Ship heel angle
Vw : wind force at sails center of effort and taken into account the heel
Vb : boat ship
VMG : Velocity made good
Pdyn = ½ Rho Vb^2 : Dynamic pressure (used in various computations)

Convergence residue		Apparent wind	
HM – RM	Thrust–Drag	awa	aws
% RM30°	% D	(°)	(Knots)

HM-RM = Heeling Moment – Righting Moment
Thrust – Drag : Thrust force (provided by the sails) – Drag force (hull and its appendages resistance)
awa : apparent wind angle
aws : apparent wind force

Sails								
Reefing	Flat	CL	CD	Ft (kN)	Fs (kN)	Mh/Fs (m)	HM (kN.m)	RM (kN.m)

Reef : input coefficient, Reef = 1 >>> above sails area and ZCE are taken unchanged
Reef < 1, for example 0,8 :
>>> sails area are reduced by (0,8) ^2 = 0,64
>>> (ZCE - Zdeck) is lower by 0,8
Flat : coefficient automatically optimised between **1** and **Flat mini** (the minimum of Flat mini being 0,5) which can numerically « flatten » the camber of the sails through the reduction of the Lift coefficient :

CL = Flat x CLo

CL , CD : Lift, Drag coefficient
Ft, Fs : Thrust and Side forces
Mh/Fs : Heeling arm
HM : Heeling Moment
RM : Righting Moment

Friction drag Dwet		Hull residuary drag Dr						Drag total
Sw hull (m2)	Dwet (kN)	Fn	> Dr/mg (%)	Dr (kN)	Dheel (kN)	Dinduced (kN)	Daero (kN)	Dtot (kN)

Sw hull : wetted surface of the hull body
Dwet : Friction drag (hull and its appendages)
Fn : Froude number
Dr/Mg : adimensional residuary drag
Dwave : residuary drag
Dheel : extra drag due to heel angle
Dinduced : induced drag (due to the lateral resistance of the hull and appendages)
Daero : aerodynamic drag (hull, rig)
Dtotal : total drag

The formulations invloved are given in the annex here after.

2.2 Reaching, for a twa betwwen 45° and 135°

The sails involved are the Main + the Jib . The User has to input the twa, a value between 45° and 135° , example with 90° :

2.2 With SA (Mainsail + Jib or Code0) and Flat = 1	**Input twa (°) between 45 and 135**	**90**

Same output as above but :

- without VMG (without interest in that case)
- with Flat maintain at 1 (no need to flatten the sails a priori)

2.3 Downwind with spi, for a twa between 90° and 180°

The sails involved are the Main + the Spi . The User has to input the twa, a value between 90° and 180° , example with 135° :

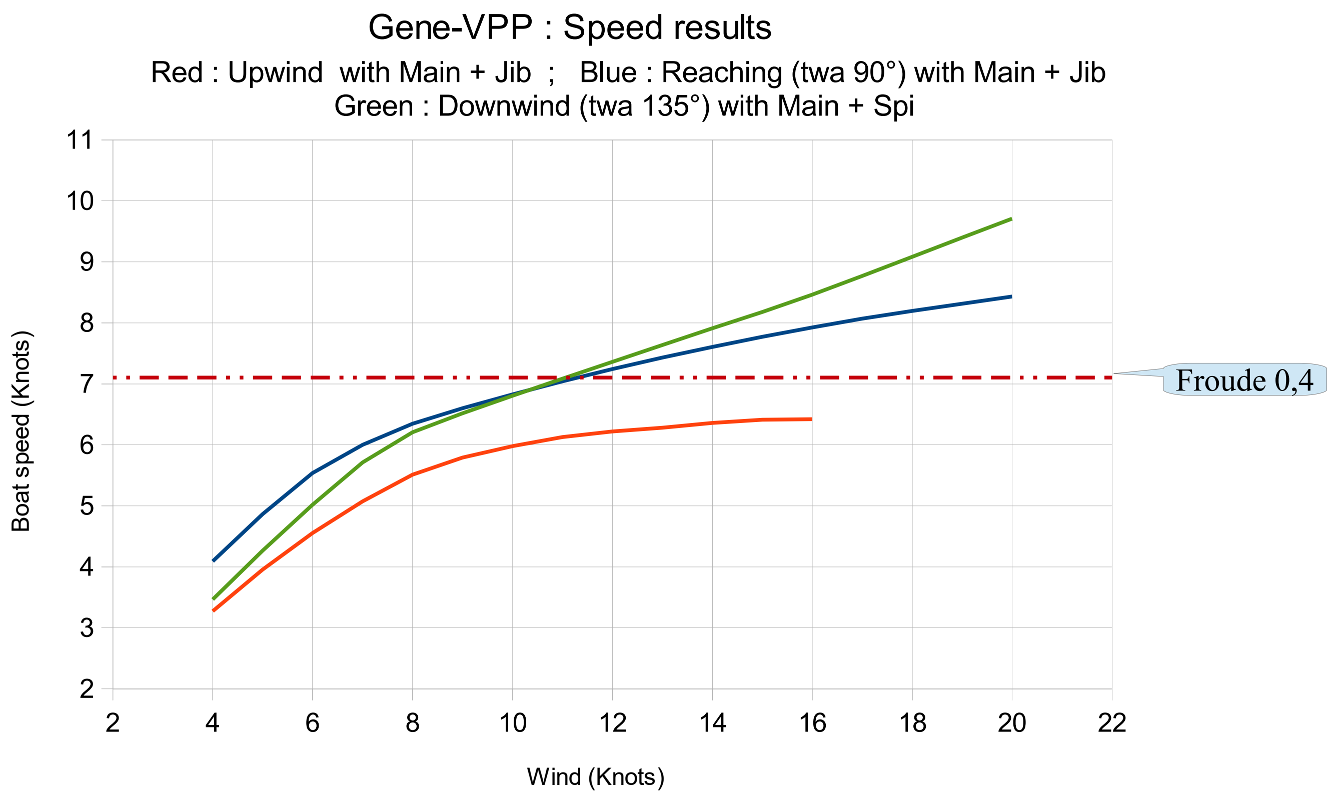
2.3 With Main + Spi (sym. or asym.)	**Input twa (°) between 90 and 180**	**135**

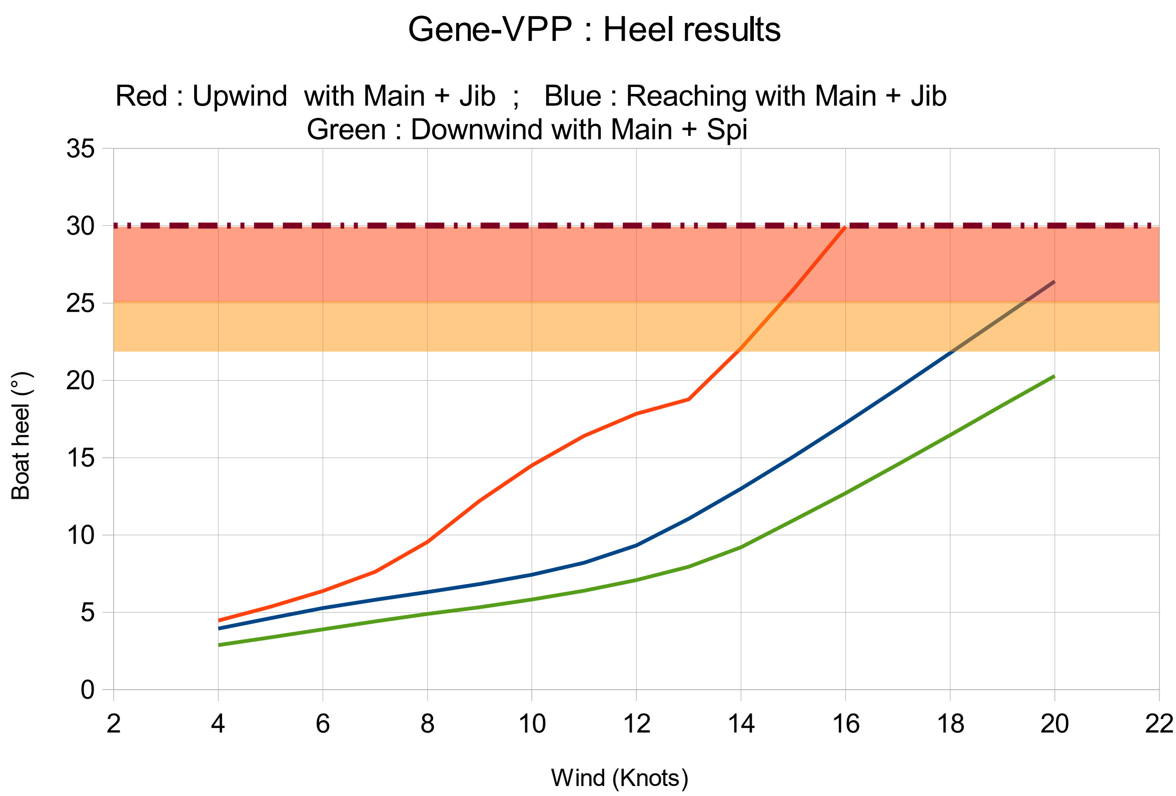
Same output as above + for the Spi :

Spi			
CL Spi	**CD Spi**	**Ft spi** (kN)	**Fs spi** (kN)

2.4 Figures about Boat speed, Heel angle, Flat optimum, Righting Moment, Drag

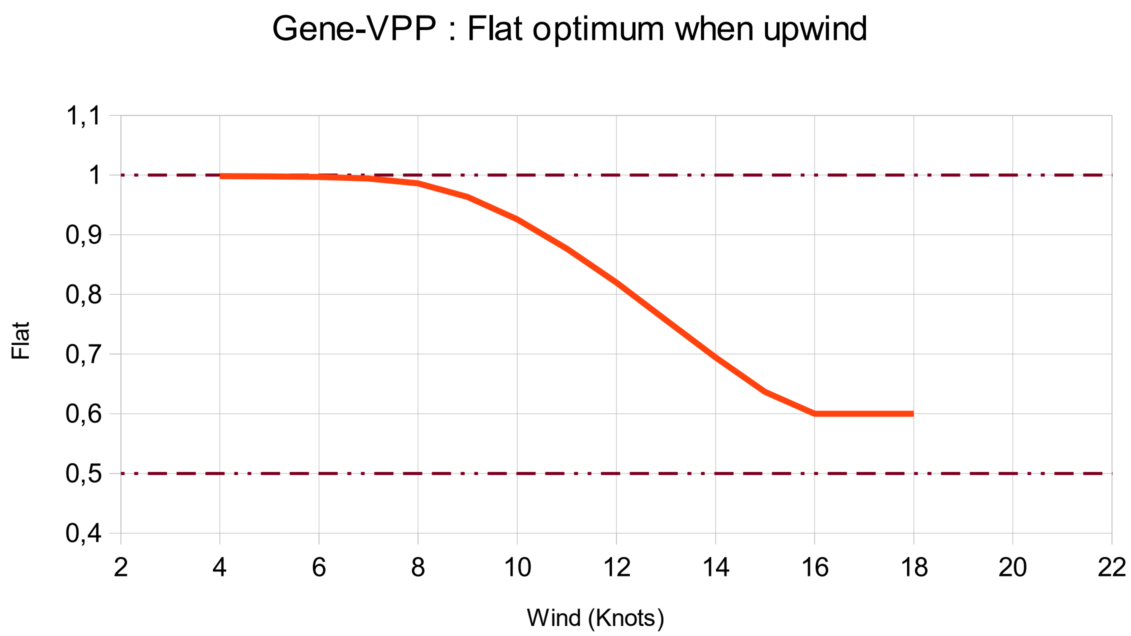
The figures are provided automatically, here below presented with the boat V1 as example :

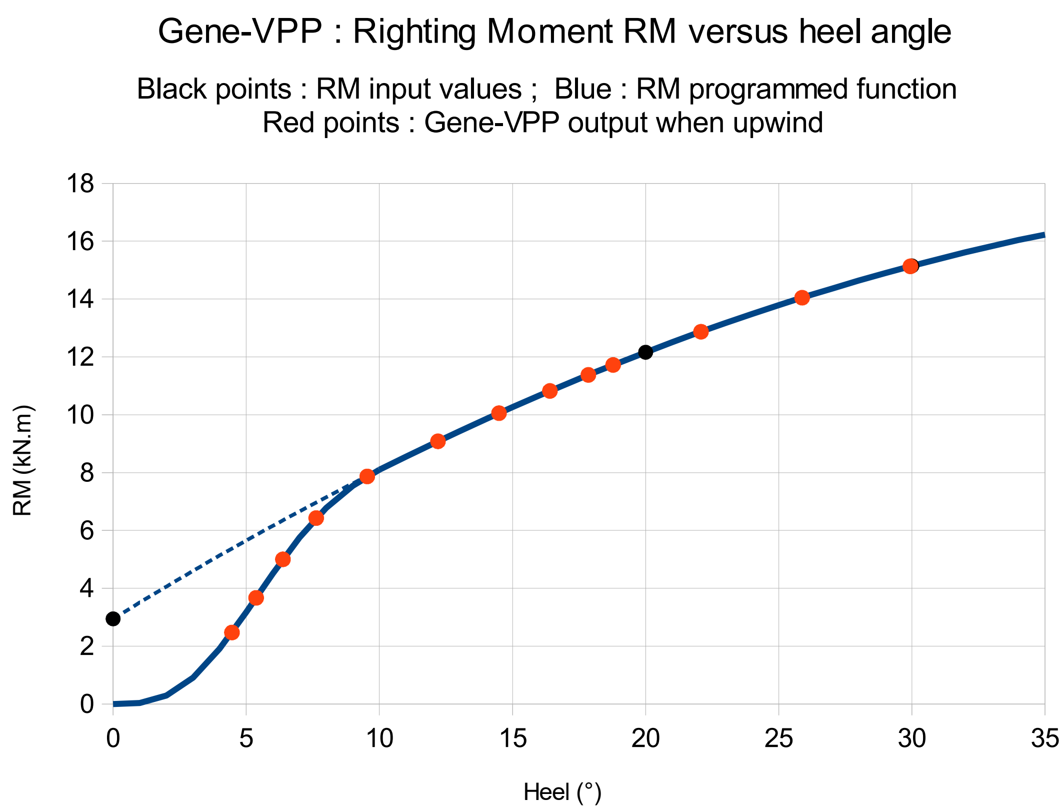


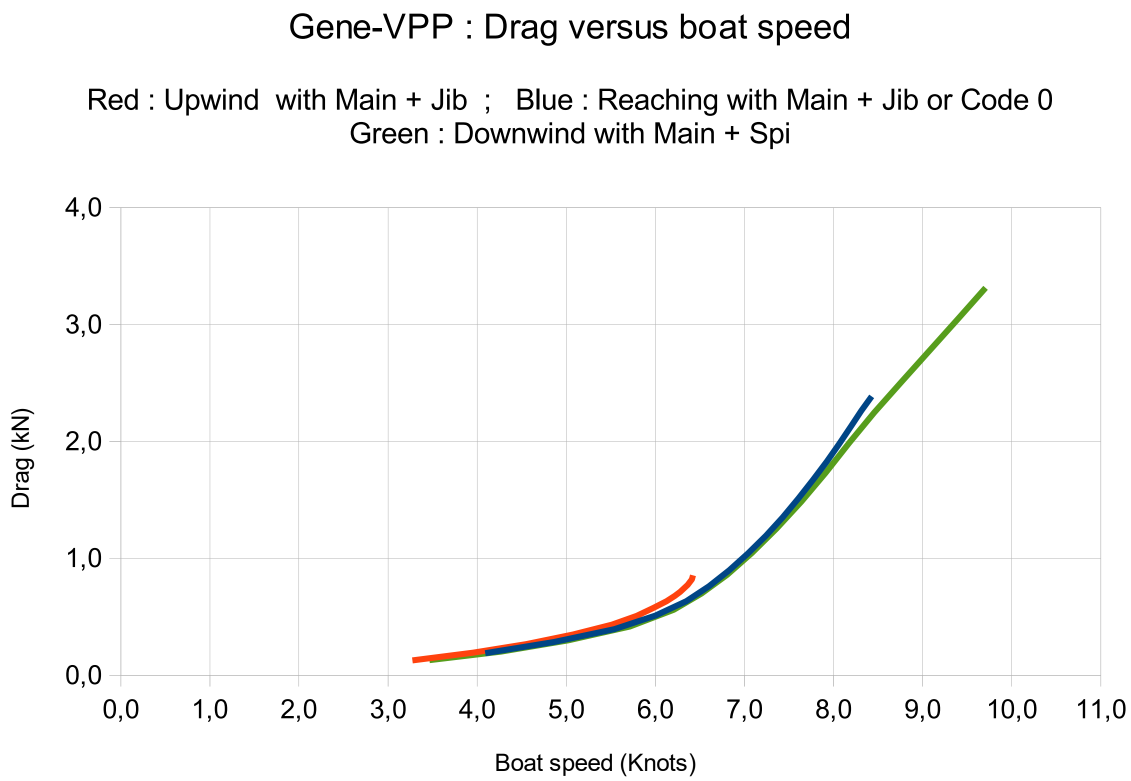


Color code for heel angle : **Orange :** 22° to 25° ; **Red :** 25° to 30°

The change of regularity of the upwind heel curve occurs when the Flat parameter reaches its authorised minimum, here example with Flat mini = 0,6






Gene-VPP : Drag versus boat speed
Red : Upwind with Main + Jib ; Blue : Reaching with Main + Jib or Code 0
Green : Downwind with Main + Spi
Drag (kN)
4,0
3,0
2,0
1,0
0,0
0,0
1,0
2,0
3,0
4,0
5,0
6,0
7,0
8,0
9,0
10,0
11,0
Boat speed (Knots)

2.5 Speed table and polar

At the beginning of the process, the table appears like here below, with the results of 2.1 Upwind on calm water already in place, and the results of 2.2 (with Mainsail + Jib) and 2.3 (With Mainsail + Spi) are recopied but to copy/special paste (format, number) in the table :

Vwind (Knts)	6	8	10	12	14	16	20	
Recopy of the 2.2 results ,	**with Mainsail + Jib (or Genoa)**							
Twa (°)	Vboat (Knts)							
90	5,54	6,35	6,83	7,24	7,61	7,93	8,43	<<< to recopy/special paste in the table here below (text, number, format)
Recopy of the 2.3 results ,	**with Mainsail + Spi (sym or asym)**							
Twa (°)	Vboat (Knts)							
135	5,02	6,21	6,81	7,36	7,91	8,46	9,71	<<< to recopy/special paste in the table here below (text, number, format)

Upwind on calm water							
Wind (Knts)	**6**	**8**	**10**	**12**	**14**	**16**	**20**
Twa (°)	43,6	42,9	42,0	41,0	40,0	39,1	38,0
Vboat (Knts)	4,55	5,51	5,98	6,22	6,36	6,42	#DIV/0 !
With Mainsail + Jib (or Genoa)							
Twa (°)							
52							
60							
75							
90							
105							
120							
135							
With Mainsail + Spi (sym or asym)							
90							
105							
120							
135							
150							
165							
180							

.... and the table, after the recopy/special paste , is :

Upwind on calm water							
Wind (Knts)	**6**	**8**	**10**	**12**	**14**	**16**	**20**
Twa (°)	43,6	42,9	42,0	41,0	40,0	39,1	38,0
Vboat (Knts)	4,55	5,51	5,98	6,22	6,36	6,42	#DIV/0 !
With Mainsail + Jib (or Genoa)							
Twa (°)							
52							
60							
75							
90	5,54	6,35	6,83	7,24	7,61	7,93	8,43
105							
120							
135							
With Mainsail + Spi (sym or asym)							
90							
105							
120							
135	5,02	6,21	6,81	7,36	7,91	8,46	9,71
150							
165							
180							

By restarting the calculation with input of other twa for the 2.2 and the 2.3 cases, respectively :

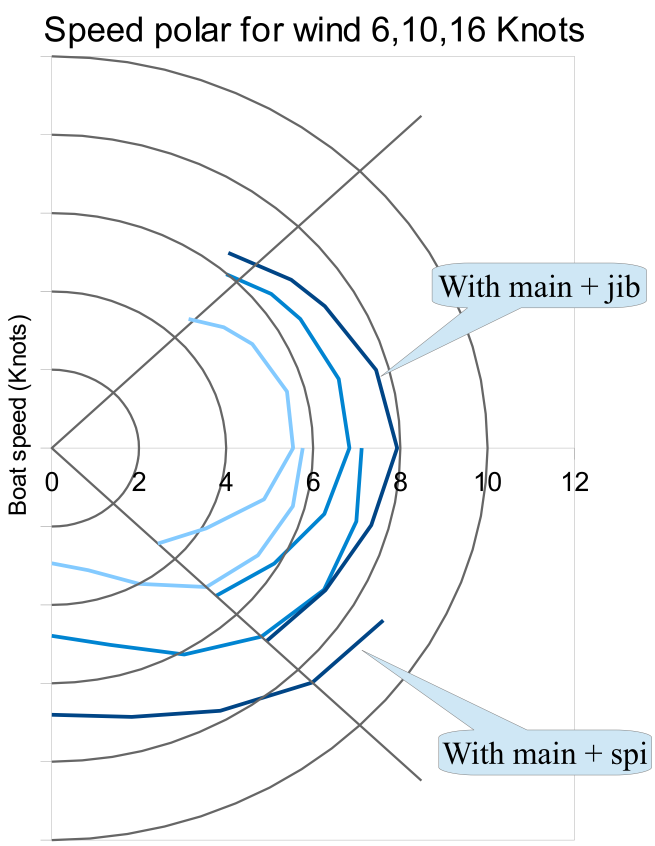
** for 2.2 : 52, 60 , 75, 90 (already done), 105, 120, 135

** for 2.3 : 90, 105, 120, 135 (alteady done), 150, 165, 180

, you can complete the table >>> example for boat V1 :

Upwind on calm water							
Wind (Knts)	**6**	**8**	**10**	**12**	**14**	**16**	**20**
Twa (°)	43,6	42,9	42,0	41,0	40,0	39,1	38,0
Vboat (Knts)	4,55	5,51	5,98	6,22	6,36	6,42	
With Mainsail + Jib (or Genoa)							
Twa (°)							
52	5,01	5,95	6,39	6,63	6,83	6,97	
60	5,31	6,19	6,59	6,84	7,06	7,24	
75	5,59	6,37	6,82	7,15	7,44	7,71	
90	5,54	6,35	6,83	7,24	7,61	7,93	8,43
105	5,04	5,95	6,47	6,87	7,25	7,60	8,16
120	4,09	5,10	5,90	6,44	6,86	7,25	7,93
135	3,44	4,43	5,33	6,04	6,55	6,97	7,75
With Mainsail + Spi (sym or asym)							
90	5,76	6,61	7,11	7,46			
105	5,73	6,63	7,24	7,71	8,05		
120	5,47	6,51	7,22	7,83	8,36	8,78	
135	5,02	6,21	6,81	7,36	7,91	8,46	9,71
150	4,00	5,16	6,08	6,70	7,22	7,74	8,94
165	3,23	4,25	5,20	6,01	6,60	7,10	8,07
180	2,94	3,89	4,79	5,65	6,30	6,81	7,73

Once the table is completed, you can recover the corresponding polar on the right side of the sheet, given for wind speed 6, 10 and 16 Knots :



Annex – Formulations and algorithms involved in SA-VPP

They are presented as programmed column by column in the spreadsheet application (under Open Office Calc), with some explanations when necessary :

Vw10 (Knots) : wind force at 10 m above the water, from 4 to 20 Knots, step 1 Knot

twa (°) : pre set true wind angle (no iteration on this parameter of which influence is second order with regard to the Flat one for the VMG optimisation)

Phi (°) : heel angle, on which the system iterates with this algorithm :

Phi(i+1) = MAX(MIN(Phi(i) + (HM(i) – RM(i))*(60/RM30°)/4; Phi(i) + 1) ; Phi(i) - 1)

i = iteration increment

HM, RM and RM30° in kN.m

To initiate the computation : Phi(0) in (°) = Vw in Knots

Vw (Knots) : wind force at sails center of effort and taken into account the heel

Vw = Vw10*LN(1000*(ZCE*Reefing)*COS(Phi/180*π))/LN(10000)

Vb (Knots) : boat speed, on which the system iterates with this algorihm :

Vb(i+1) = MAX(MIN(Vb(i)+(Thrust(i) – Drag(i))*(14000/Disp)/10; Vb(i) + 0,1); Vb(i) - 0,1)

i = iteration increment

Thrust, Drag in kN

Disp. = Displacement in kg

To initiate the computation :
Upwind : Vb(0) = (Vw/20)^0,5*[0,35*(9,81*Lwl)^0,5*36/18,52]
Beam reaching twa 90° : Vb(0) = (Vw/20)^0,5*[0,43*(9,81*Lwl)^0,5*36/18,52]
Beam reaching twa 90° : Vb(0) = (Vw/20)^0,75*[0,43*(9,81*Lwl)^0,5*36/18,52]
with Vw in knots and Lwl in m

VMG (Knots) : Velocity Made Good

VMG = Vb*COS(Phi/180*π)

Vb (m/s) : Boat speed in m/s unit

Vb(m/s) = Vb(Knots)*18,52/36

Pdyn = ½ Rho Vb^2 : Dynamic pressure

Pdyn = ½ Rho Vb^2 = 0,5*1025*Vb(m/s)^2

awa (°) : apparent wind angle

awa = ATAN(Vw*SIN(twa/180*π)*COS(Phi/180*π)/(Vw*COS(twa/180*π)+Vb))*180/ π
and awa = IF(awa<0;180+awa;awa) ; Vw and Vb in same unit

aws (Knots) : apparent wind speed

aws = Vw*SIN(twa/180*π)*COS(Phi/180*π)/SIN(awa/180*π)

HM – RM : Residue of the convergence as regard the heel moments equilibrium

Thrust – Drag : Residue of the convergence as regard the forces equilibrium

Thrust = Ft or (Ft main + Ft spi when downwind) , see here after
Drag = Dtotal , see here after

Sails forces and heeling moment :

Reef : input coefficient, Reef = 1 >>> input sails area and ZCE are taken unchanged
Reef < 1, for example 0,8 :
>>> sails area are reduced by (0,8) ^2 = 0,64
>>> (ZCE - Zdeck) is lower by 0,8

Flat : coefficient between 1 and Flat Mini which can numerically « flatten » the camber of the sails through the reduction of the Lift coefficient. For the search of an optimum, this algorithm is used :

Flat(i+1) = MAX(MIN(Flat(i)-(HM(i)-RM(i))/RM30°*k; 1); Flat mini)

with i = iteration increment
Flat(0) =1
k = 0,02 when Vw = 4 Knots
0,04 when Vw = 5 Knots
0,06 when Vw = 6 Knots
0,08 when Vw = 7 Knots
0,10 when Vw = 8 to 20 Knots

For the configuration Mainsail + Jib :
SA : 0,89 *(S Main + S Jib) ; SA being the sails area taken into account as a whole for the configuration without spi, with the **CL , CD coefficients** (Lift, Drag) such as :

CL = Clo*Flat and **CD =** Cdo + CL^2/π/AR
, with Clo and Cdo are based on :

Apparent wind angle awa (°)	awa 26°	awa 45°	awa 65°	awa 85°	awa 115°	awa 180°
CLo	1,3	1,5	1,2	1,2	0,7	0,0
Cdo	0,02	0,02	0,15	0,8	1	0,8

AR = Aspect ratio estimation of the sailplan
AR = (1,1*Zmast)^2/SA

For the configuration Mainsail + Spi :
the CL, CD of the Mainsail are the ones here above and the **CLspi**, **CDspi** coefficients for the Spi are based on :

Coeffs basis for Spi sym				
awa (°)	**50**	**80**	**100**	**180**
CL Spi	0,74	1,49	1,22	0,00
CD Spi	0,21	0,59	0,88	0,78
Coeffs basis for Spi asym				
CL Spi	1,05	1,56	1,30	0,00
CD Spi	0,20	0,55	0,81	0,32

Ft (kN) : Sails thrust force (with SA , configuration main + jib)

Ft = (0,5*ρair*(aws*18,52/36)^2)*(SA*Reef^2)*[CL*COS((90-awa)/180*π) - CD*COS(awa/180*π)]/1000
with ρair = 1,225 kg/m3

Fs (kN) : Sails side force (with SA , configuration main + jib)

Fs = Kfy*(0,5*ρair*(aws*18,52/36)^2)*(SA*Reef^2)*[CL*SIN((90-awa)/180*π + CD*SIN(awa/180*π)]/1000

with KFy = 1,05 Upwind ; 1,20 Beam Reaching & Downwind
(it is a coefficient which compensates for the simplification of a unique sailplan and allows a good comparison with commercial VPPs)

When downwind with main + spi : we consider the mainsail with its surface in the Ft, Fs formulations above + for the spi forces such as :

Ft spi (kN) = (0,5 * ρair * (aws*18,52/36)^2) * (Spi*Reef^2) * [Clspi*COS((90-awa)/180*π) - CDspi*COS(awa/180*π)] / 1000

Fs spi (kN) = (0,5 * ρair * (aws*18,52/36)^2) * (Spi*Reef^2) * (Clspi*SIN((90-awa)/180*π) + CDspi*SIN(awa/180*π)) / 1000

Ha (m) : Heeling arm

Ha = Zdeck + (ZCE-Zdeck)*Reef + 0,45*Draft

HM (kN.m) : Heeling Moment

HM = Ha * Fs

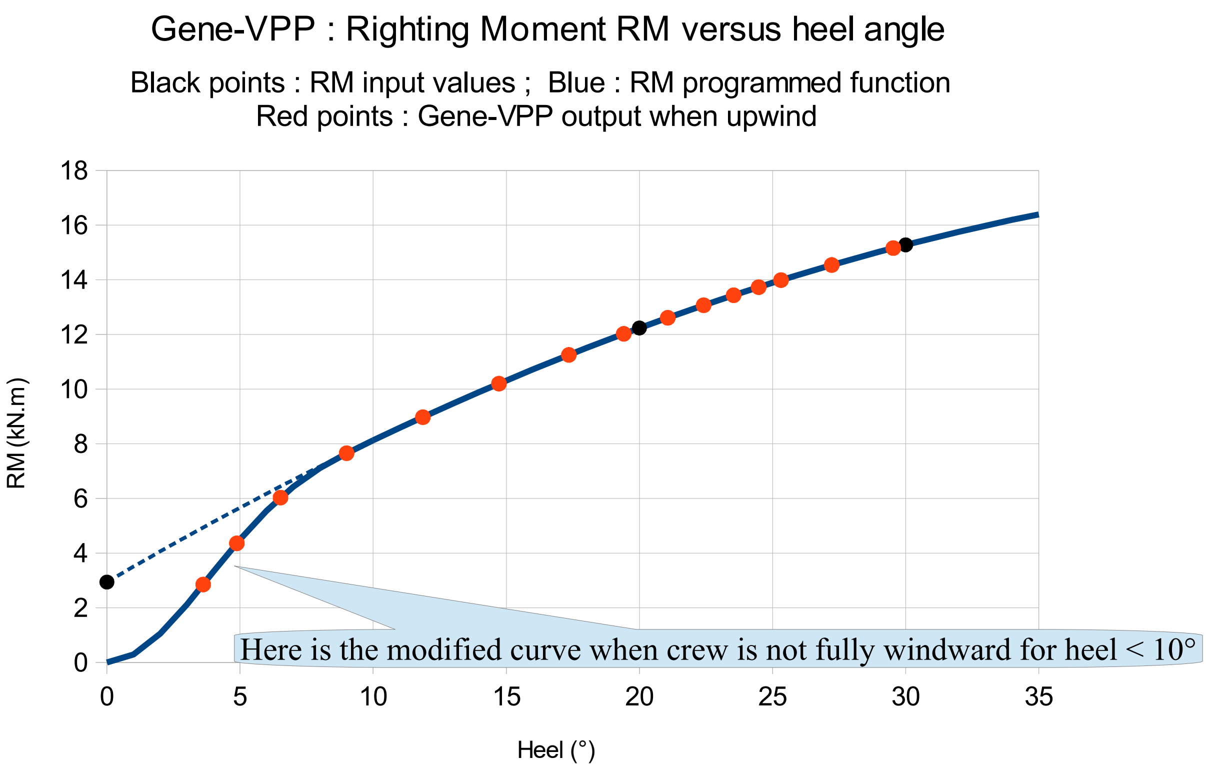
Righting Moment :

RM : Righting Moment. The formulation is a quadratic polynome in Phi (the heel angle) and based on RM0°, RM20° and RM30° input + a correction for Phi (0,10°) to take into account that the crew is moving progressively from the center to a windward sit in this range of heel.

RM = IF(Phi<10;DRM*Phi^2+ERM*Phi;ARM*Phi^2+BRM*Phi+CRM)

with ARM = (30*(RM20°-RM0°)-20*(RM30°-RM0°))/(20^2*30-30^2*20)
BRM = ((RM20°-RM0°)-ARM*20^2)/20
CRM = RM0°
DRM = (RM10°-10*RM10')/(-100)
ERM = RM10'-20*DRM
RM10° = ARM*100+BRM*10+CRM
RM10' = ARM*20+BRM

Example here below : *where one can see the curve change between 0° and 10° to take into account that the crew is moving progressively from the center to a windward sit in this range of heel.*



Friction Drag :

Sw hull : wetted surface of the hull body. The formulation is a quadratic polynome in Phi (the heel angle) and based on Sw0°, Sw20° and Sw30° input.

Sw hull = A_{Sw}*Phi^2+B_{Sw}*Phi+C_{Sw}

with A_{Sw} = (30*(Sw20°-Sw0°)-20*(Sw30°-Sw0°))/(20^2*30-30^2*20)
B_{Sw} = ((Sw20°-Sw0°)-A_{Sw}*20^2)/20
C_{Sw} = Sw0°

RE hull : Reynolds number applied for the hull body

Re hull = Vb*(0,7*Lwl)/v (0,7 is recommended by L. Larrson and R. Eliasson in their « Principles of Yacht Design » book)

with Vb = Boat speed in m/s unit
v = cinematic viscosity of sea water = 1,0 E-6 m2/s

Cf hull : friction coefficient of the hull surface

Cf hull = 0,075/(LOG(Re hull;10)-2)^2

Re keel : Reynolds number applied for the keel wing

Re keel = Vb*(Chord)/v

with Chord : root chord of the keel wing (m)

Cf keel : friction coefficient of the keel wing surface

Cf hull = 0,075/(LOG(Re keel;10)-2)^2

Re bulb : Reynolds number applied for the keel bulb (if any)

Re keel = Vb*(L bulb)/v

Cf bulb : friction coefficient of the keel bulb surface

Cf hull = 0,075/(LOG(Re bulb;10)-2)^2

Re rudder: Reynolds number applied for the rudder (inc. its skeg if any)

Re keel = Vb*(Chord)/v

with Chord : root chord of the rudder (m)

Cf keel : friction coefficient of the rudder surface

Cf hull = 0,075/(LOG(Re rudder;10)-2)^2

Dwet (kN) : Friction drag (hull and its appendages)

Dwet = Pdyn*(Cf hull*Sw hull+Cf keel*Sw keel+Cf bulb*Dcf*Sw bulb+Cf rudder*Sw rudder)/1000

with Dcf = 1+1,5*(D bullb/L bulb)^1,5+7*(D bulb/L bulb)^3

Residuary Drag Dr :

Fn : Froude number

Fn = Vb/(9,81*Lwl)^0,5

The adimensional residuary drag, i.e. Dr/Mg in function of Fn, can be derived from the Delft series output, the formulations and the coefficients proposed by L. Larsson and R. Eliasson in their book « Principles of Yacht Design » 2nd Edition 2000.
Two formulations are proposed by the authors to cover Fn up to 0,75 :

For Fn < 0,45 :

Dr/Mg (%) = (a0 + a1*Cp + a2*LCB + a3*Bwl/Tc + a4*Lwl/D^(1/3)+ a5*Cp^2 + a6*Cp*Lwl/D^(1/3) + a7*LCB^2 + a8*(Lwl/D^(1/3))^2 + a9*(Lwl/D^(1/3))^3)/1000*100

with D (m3) = Displacement of the hull body
D = (Disp./1025 - Vol. Keel – Vol. Bulb – Vol. Rudder)
LCB = LCB hull (%Lwl) – 50
Cp = Cp hull
Coefficients « ai » are given for Froude Fn = 0,175 to 0,450 :

	a0	a1	a2	a3	a4	a5	a6	a7	a8	a9
Fn 0,175	-1,503526	24,408030	0,012200	0,067221	-2,448582	-31,913700	2,216098	0,000074	0,244345	-0,015887
Fn 0,200	11,29218	-14,51947	0,047182	0,085176	-2,673016	-11,41819	5,654065	0,007021	-0,094934	0,006325
Fn 0,225	22,17867	-49,16784	0,085998	0,150725	-2,878684	7,167049	8,600272	0,012981	-0,327085	0,018271
Fn 0,250	25,90867	-74,75668	-0,153521	0,188568	-0,889467	24,12137	10,48516	0,025348	-0,854940	0,048449
Fn 0,275	40,97559	-114,2855	0,207226	0,250827	-3,072662	53,0157	13,02177	0,035934	-0,715457	0,039874
Fn 0,300	45,83759	-184,7646	0,357031	0,338343	3,871658	132,2568	10,86054	0,066809	-1,719215	0,095977
Fn 0,325	89,20382	-393,0127	0,617466	0,460472	11,54327	331,1197	8,598136	0,104073	-2,815203	0,155960
Fn 0,350	212,6788	-801,7908	1,087307	0,538938	10,80273	667,6445	12,39815	0,166473	-3,026131	0,165055
Fn 0,375	336,2354	-1085,134	1,644191	0,532702	-0,224173	831,1445	26,18321	0,238795	-2,45047	0,139154
Fn 0,400	566,5476	-1609,632	2,01609	0,265722	-29,24412	1154,091	51,46175	0,288046	-0,178354	0,018446
Fn 0,425	743,4107	-1708,263	2,435809	0,01553	-81,161189	937,4014	115,6006	0,365071	1,838967	-0,062023
Fn 0,450	1200,62	-2751,715	3,208577	0,25492	-132,0424	1489,269	196,3406	0,528225	1,379102	0,013577

For Fn = 0,475 to 0,75 :

Dr/Mg (%) = (a0 + a1*(Lwl/Bwl) + a2*(Sf/D^2/3) + a3*LCB + a4*(Lwl/Bwl)^2 + a5*(Lwl/Bwl) *(Sf/D^2/3)^3) /1000*100

Coefficients « ai » are given for Froude Fn = 0,475 to 0,75 :

Fn 0,475 a0	a1	a2	a3	a4	a5
180,1004	-31,50257	-7,451141	2,195042	2,689623	0,00648
Fn 0,50 a0	a1	a2	a3	a4	a5
243,9994	-44,52551	-11,15456	2,17905	3,85740	0,009676
Fn 0,55 a0	a1	a2	a3	a4	a5
313,4109	-56,58257	-14,41978	2,326117	4,690432	0,012147
Fn 0,60 a0	a1	a2	a3	a4	a5
356,4572	-62,85395	-16,85112	2,437056	5,078768	0,014980
Fn 0,65 a0	a1	a2	a3	a4	a5
301,1268	-39,79631	-15,02299	2,099657	2,545676	0,013588
Fn 0,70 a0	a1	a2	a3	a4	a5
284,4641	-25,14558	-16,15423	1,703981	0,817912	0,014575
Fn 0,75 a0	a1	a2	a3	a4	a5
304,1803	-30,11512	-15,85429	2,863173	1,524379	0,014031

Limits of validity for both formulations :

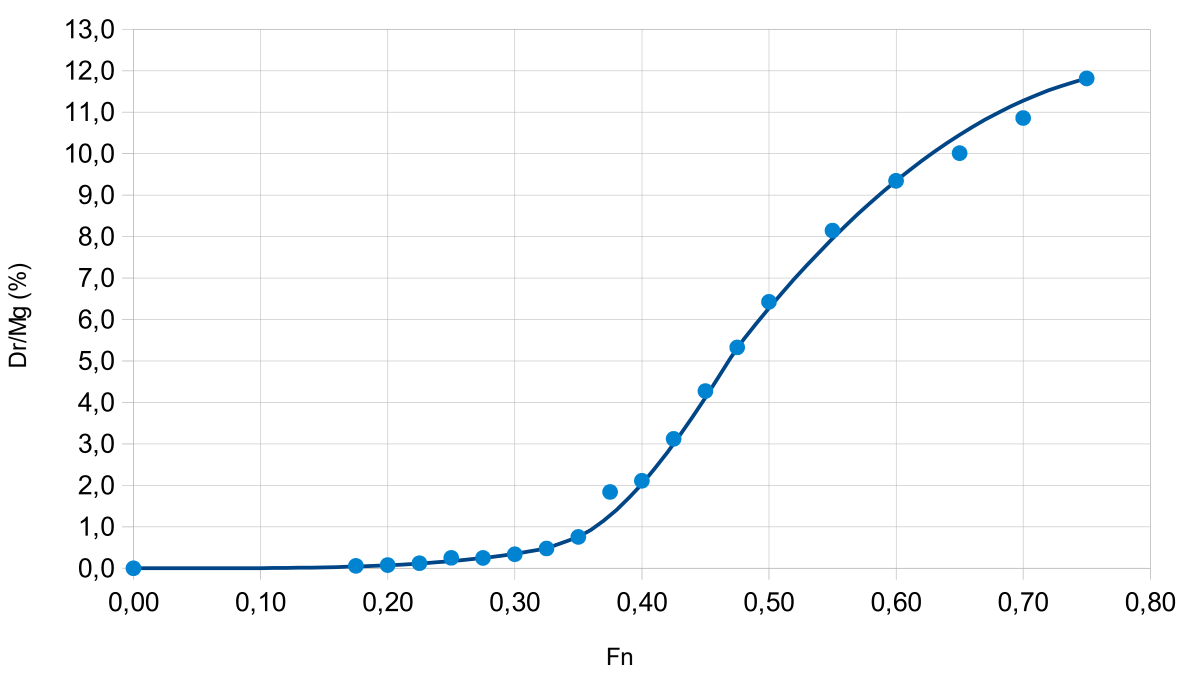
Lwl/Bwl	Bwl/Tc	Lwl/D^1/3	Cp	LCB
(2,76 5,0)	(2,46 19,32)	(4,34 8,50)	(0,52 0,60)	(0,0 -6,0)

From these data, a curve for Dr/Mg is built with 3 successive interpolation functions F1, F2 and F3 of Fn : F1 for Fn 0 to 0,35 ; F2 for Fn 0,35 to 0,475 ; F3 for Fn 0,475 to 0,75

Example :

Residuary Drag / Disp. hull (%)

Blue points : from "PYD" formulations ; Blue curve : as programmed in the VPP



Dr/Mg (%) : adimensional residuary drag in %

Dr/Mg (%) = IF(Fn<0,35; F1; IF(Fn<0,475; F2; F3))

Dr (kN) : residuary drag

Dr = (Dr/Mg(%)/100)*(D*1025)*9,81/1000

with D (m3) = Displacement of the hull body
D = (Disp./1025 - Vol. Keel – Vol. Bulb – Vol. Rudder)

Dheel (kN) : extra drag due to heel angle

Dheel = Pdyn*Sw hull*Ch*Fn^2*(Phi/180*π)/1000

with Ch = [6,474*(Tc/T)+2,517*(Bwl/Tc)+3,71*(Bwl/Tc)*(Tc/T)]/1000
Tc, T : respectively hull body draft, overall draft

Dinduced (kN) : induced drag (due to the lateral resistance of the hull and appendages)

The lateral surface which resists to the drift (hull, keel, rudder) is assimilated to a half-wing of which the other half is mirrored in relation to the surface of the water and so, applying the lifting line theory , we have :

Fs = Pdyn S cos(Phi) CL and Dinduced = Pdyn S cos(Phi) CL^2 / (π AR)

, with :
S = lateral surface considered
CL = lifting coefficient of this lateral surface
AR = aspect ratio of the equivalent half-wing

As we know Fs but not CL (the lift coefficient), one can eliminate CL between the 2 equations :

>>> Dinduced = Pdyn S cos(Phi) [Fs^2 / (Pdyn S cos(Phi) $)^2$] / (π AR)

>>> Dinduced = Fs^2 / [Pdyn cos(Phi) π S AR]

Claughton, in « Developments in the IMS VPP Formulations » Andrew Claughton, Wolfson Unit MTIA, University of Southampton, UK » proposes to replaces the aspect ratio AR by the equivalent B2 / Area of a wing in which B = wingspan = 2 Teff (Draft "effective") and A = 2 S (total lateral surface)

>>> the product S AR becomes = S (2 Teff$)^2$ / (2 S) = 2 $Teff^2$

, and Dinduced = Fs^2 / [Pdyn cos(Phi) π 2 $Teff^2$]

, in which Teff is named the effective draft, itself estimated by Teff = 0,92 T_R , a "reduced draft" calculated according to several data (local section maximum draft, hull cross sectional area).

Claughton quotation :

> Equation 8 is based on simple aerodynamic theory for the induced drag of a lifting surface of finite span. It is interesting to note that induced drag depends only on keel effective draft, the keel aspect ratio per-se does not affect induced drag. Keel lateral area affects the sailing leeway angle and the local keel lift coefficient, but does not affect induced drag.
>
> $$D_I = {F_H}^2 \Big/ \pi \rho V^2 T_{EFF}^2 \qquad [8]$$
>
> $$T_{EFF} = 0.92 T_R = \text{IMS D}$$
>
> The value of the effective draft (T_{EFF}) is determined by the LPP using the original expression for a "reduced draft" (T_R) which is calculated based on the local section maximum draft and hull cross sectional area. This expression which treats the hull and keel as one half of a slender axisymmetric body, calculates the effect of streamline contraction around the canoe body. In this way the influence of a deep hull on effective draft is accounted for.

This approach is interesting in my opinion because it is simpler and eliminates the product S AR, but it does not ultimately avoid hypotheses and coefficients to determine this Teff. So for Gene-VPP purpose, I propose a simple approach requiring only one calibration appraoch :

Dinduced = Fs^2 / [Pdyn cos (Phi) π (**1,2** T^2+ **0,8** (T – Tc)^2)]

, with T = Draft and Tc = Hull body Draft

, where the « calibration » is in the coefficients 1,2 and 0,8 (of which sum should be = 2)

Within Gene-VPP , that leads to this formulation :

Dinduced (kN) = (Fs*1000)^2/Pdyn/COS(Phi/180*π)/π/(1,2*T^2+0,8*(T-Tc)^2)/1000

Daero (kN) : aerodynamic drag (hull, rig)

Daero = 0,5 * ρ_{air} * (aws*18,52/36)^2 * ABS(COS(awa/180*π)) * COS(awa/180*π) * (Bmax*Zdeck*0,4 + Zmast^2*0,01*0,2) /1000

Note : when Downwind with the spi, Daero is not taken into account (a tiny thrust in such case)

Dtotal (kN) : total drag, to put equal to Thrust (= Ft)

« **Drag » =** Dtotal = Dwet + Dr + Dheel + Dinduced + Daero