UliSail

Vers. 3.6

User's Manual

latest update available at
www.remmlinger.com

UliSail.exe was compiled with the Intel® Fortran compiler for Windows. When you start it for the first time, some OS can block the execution and display a message that UliSail might contain a risk to your computer. The reason for this message is the fact, that UliSail comes without a certificate and Microsoft tries to enforce its own certification process. Since UliSail is free software, it is impossible to buy every year an expensive new certificate. You can click on the information button in the message, "accept the risk" and run the program.

Contents

1 INTRODUCTION

UliSail is a program that computes the aerodynamic forces for sailing yachts with a head- and mainsail. It uses Prandtl's lifting-line method. The theoretical background is explained in [1] and should be studied. It can also optimize the trim parameters and maximize the driving force. Together with UliLines and UliTank it is the third module that will finally form a VPP. The aim of my work is the extended use of the computer in the design spiral. The computer is an ideal tool when it comes to multiple iteration loops as in the optimization process for the design of a sailing yacht. Details can be found on my website www.remmlinger.com.

Compared to the initial version, in 3.1 a few errors were corrected, the part of the headsail below the clew has now a more realistic shape, additional parameters for the distribution of camber and twist on the jib were added and the estimate for the leeway was improved. Additional updates included the possibility to check if the spreader or the shroud intrudes into the headsail and a reefing option for the mainsail. The mast profile can now be tapered. Also the 2D-coefficients for the mainsail were modeled more realistically. Update 3.6 produces script-files that can be read by Rhino, which will create 3D-surfaces of the sails after a mouse-click.

2 INSTALLATION OF THE PROGRAM

The zipped file that you downloaded contains the executable file UliSail.exe, an input file in the subdirectory INPUT, examples of output files in the subdirectory USL and this manual. You should extract these files into a folder of your choice. Nothing else will be installed on your computer. You can run the program within its folder. It requires a Windows operating system for 64-bit architecture. The subdirectories should not be renamed or deleted. The additional file D33.xlsx contains several sheets with diagrams. It shows you, how the output files can be used, to illustrate the results. If you want to uninstall the program, you just need to delete the complete folder UliSail. On today's machines with several cores, it is possible to run several copies of UliSail in parallel. This will speed up the task, when a polar diagram for different courses is desired. You can copy the complete folder in this case and rename the program UliSail2.exe etc.

3 THE INPUT FILE

The purpose of this file is the collection of the geometric parameters of the rig and the input of the environmental conditions. The input file is built by a sequence of line-pairs. The first line always contains an explanation and the second line the numerical value of the parameter. The program reeds only every second line and in that line only the first number until the first blank behind this number. The rest of the line is ignored. This is convenient if you want to test different values for a parameter and you want to memorize what has been tested: just move it to the right and type the new value in the left-most position. The input parameters are not all checked for plausibility. You can easily crash the program when you specify silly values.

As an example we will calculate the sail forces for a Dehler 33. Let's inspect the file USL_D33_in.txt line by line:

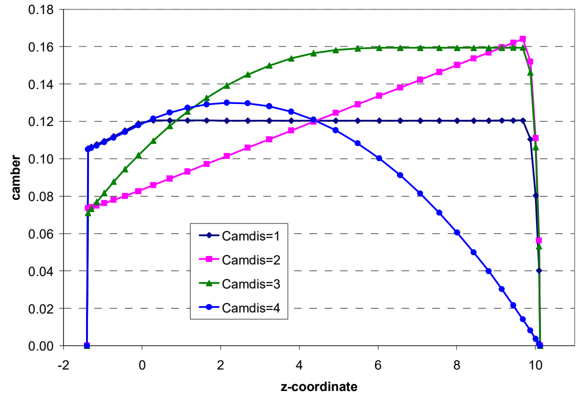
```
Headline:
*    Dehler 33      *
AIRTMP = air temperature in Deg. Celsius
   15.0
VTW10  = true wind speed at 10 meters hight in (kts)
   10.
```

In the second line, the user can type a description of the yacht or of the project. This headline will also appear in the output files. In the 4^{th} line the ambient air temperature is specified and in the 6^{th} line the true wind speed at a height of 10 meters in knots. The following parameters define the geometry of the headsail. The DWL is the designed waterline.

```
LMAST  = length of mast above deck level in (m)
   14.46
SAILI  = vertical height fom deck level to mast fitting of forestay = "I" in (m)
   12.
REEFI = vertical height of head of foresail above deck in % of "I"
   96.
SAILJ  = horizontal distance on deck from forestay to front of mast = "J" in (m)
   3.42
LPMAX  = maximum of "luff perpendicular" measured at right angle from forestay to clew in % of "J"
   142.
HTACK  = height of the lower end of the forestay above the DWL in (m), assumed to be general deck level
   1.18
HCLEW  = height of clew of foresail above deck in (m)
   0.7
PROFIL = profile of headsail: NACA-mean = 1, parabola = 2
   1
SHEETA = sheeting angle from tack to jib-car on deck in degr. Sheet at foot rail = 100.
   10.
CAMDIS = distribution of camber for the Jib. 1=constant, 2=linear, 3=parabolic, 4=decreasing
   3
RTWISTJ = reduction of twistcurve in the middle of the jib in degr.,-5.< RTWIST <5., linear=0.
   0.
```

With PROFIL the profile of the headsail can be specified. Profile no. 1 uses a NACA-mean line, whereas profile no. 2 exhibits the contour of a parabola. When sailing close-hauled upwind profile 1 will give higher driving forces, but for true wind angles >70° the parabola will give better results. The maximum camber for profile 1 is 18% and for profile 2 it is 36%. SHEETA defines the sheeting point of the headsail on deck. The sheeting angle is measured on deck from the centerline to a line from the chainplate of the forestay to the car on the genoa track. The clearance of the sail to the shrouds and spreaders must be observed. On reaching courses it is better to lead the sheet to the foot-rail. Insert 100. in this case. For a large SHEETA, the position of the jib sheet block might be beyond the foot-rail. In this case, the program will tell you, to use a whisker-pole.

The parameter CAMDIS defines the distribution of the camber on the headsail. The number 1 stands for a constant camber on the entire sail. If number 2 is specified, the camber will increase linearly from foot to top, with number 3 the camber will follow a parabolic curve and with number 4 the camber will decrease towards the head. Sailmakers prefer curve 3. In heavy winds curve 4 is helpful to decrease heel.



RTWISTJ modifies the sheeting angle of the jib. If it is set to zero, the angle will increase linearly from foot to top. Measurements of the flying shape on the sailing dynamometer Fujin showed that the top of the sail could twist more under the wind pressure, than the middle of the sail. In this case, the middle of the sail might have a sheeting angle that is 3° reduced compared to the linear distribution. In such a case, RTWISTJ can be set to 3.

The following parameters define the geometry of the spreaders and the position of the shroud. If LSPRED is larger than zero, the program will check, if the spreader intrudes into the headsail. If this happens, it is necessary to increase X3, or X4, or SHEETA, to increase the distance of the sail to the spreader.

```
LSPRED  = length of the upper spreader in (m), if no check required = 0.
   0.69
ANGSPR  = sweep-back angle of the upper spreader in deg.
   20.
ZSPRED  = height of the upper spreader above the boom in (m)
   6.94
LSPRDL  = length of the lower spreader in (m)
   0.9
ZSPRDL  = height of the lower spreader above the boom in (m)
  3.04
DCHNPL = distance of shroud-chainplate from centerline in (m) , if no check required = 0.
  0.91
```

The following parameters describe the mainsail. The mast diameter to the third power (Dmast)^3 will decrease linearly to the top.

```
SAILP  = vertical length of the luff of the mainsail along the mast = "P" in (m)
   12.8
REEFP = vertical height of head of mainsail above the boom in % of "P"
  100.
SAILE  = horizontal length of the foot of the mainsail along the boom = "E" in (m)
   4.7
MHEAD  = horizontal length of the head for sqare top mainsail in (m), use 0. for pinhead rig
   0.1
```

```
CAMAIN = camber of mainsail: 1 = best lift/drag-ratio, 2 = not less than 6%
   2
RTWISTM = reduction of twistcurve in the middle of the mainsail in degr.-5.<RTWIST<5.,linear=0
   3.
HBOOM  = height of the boom above the DWL in (m)
   2.58
MBOOMA = maximum boom-angle when touching the shrouds, in degr.
   75.
DMAST1  = long axis of elliptic mast section at goosneck in (m)
   0.13
DMAST2  = DMAST at head of unreefed mainsail, in (m)
   0.07
AMAIN  = true area of mainsail in (m2) to calculate roach
   35.4
ASTRIG = total lateral area of standing rigging without mast in (m2) for parasitic drag
   0.48
```

The maximum camber of the mainsail is 18%, the profile uses the NACA-meanline. `RTWISTM` is defined in the same way as `RTWISTJ`. The parameter `CAMAIN` is introduced to control the camber of the mainsail. Depending on the angle of attack, the program uses the camber that gives the best lift to drag ratio for the given flow conditions. The result is a very flat profile at the foot of the main, which is often not realistic or difficult to produce. `CAMAIN` = 2 will avoid these flat areas and will allow only a camber of at least 6%. The difference in boat speed is very small, only the shape of the sail will change.

Several parameters are required to describe the righting moment of the yacht

```
KM     = metacentric height above keelpoint K at zero heel in (m)
   1.64
KG     = distance from center of gravity to keelpoint K in (m)
   0.44
BALLR  = ballast ratio in %
   30.16
DISPL  = weight displacement in (kg), including the weight of the crew
   3950
CREWKG = weight of the crew on the rail in (kg)
   0
```

If the metacentric height `KM` is unknown, a simple approximation, proposed by Gerritsma [2] can be used:

$$KM = 0.664 \cdot T_{CB} + 0.111 \cdot \frac{{B_{WL}}^2}{T_{CB}}$$

The keelpoint K is the deepest point of the canoe body (CB). The center of gravity is often close to the DWL. In such a case case, $KG \sim T_{CB}$.

The following parameters are required to define the hull:

```
LOA    = length of hull, without pulpit, in (m)
    10.
LWL    = length of immersed hull at waterline in (m)
    9.12
BWL    = max. beam of hull at waterline in (m)
    2.41
BDECK  = maximum beam of hull on deck in (m)
    3.0
XBDMAX = distance from mast to position of BDECK in (m)
    2.46
BDECK0 = beam of hull on deck directly behind the mast in (m)
    2.45
DRAFT  = maximum draft, including keel in (m)
    2.0
TCB    = draft of canoe body, without keel in (m)
    0.408
CM     = midship section coefficient for calculation of wetted surface
    0.761
```

```
CKTOP  = chordlength of keel at upper end in (m)
    0.92
CKLOW  = chordlength of keel at at lower end, without bulb, in (m)
    0.88
```

The description of the keel is needed to determine the induced resistance of the keel under leeway.

The next parameters define the apparent wind angle:

```
VBOAT  = Speed of the boat over ground in knots
   6.1
BETATW = true wind angle relative to x-axis in degr.
   41.
DELTA  = leeway (drift) angle over ground in degr.
   4.
```

If the boatspeed is unknown, it can be taken from ORC-data https://jieter.github.io/orc-data/site/. It is necessary to supply an estimate for the leeway angle delta. The program will give at the end a best guess for `DELTA` at the optimum that has been reached. If there is a large difference between the initial `DELTA` and the most likely value at the optimum, the program should be restarted with a better guess for `DELTA`.

The next four values are the initial starting values for the trim parameters. The angles must be inserted in radian. The conversion factor is:

$$\text{angle in radian} = (\text{angle in degrees}) \cdot \pi / 180$$

It is possible to type `100.` in individual places, in this case a default value will be used.

```
X1 = Sheeting angle mainsail at boom in (rad)
   0.
X2 = twist mainsail in (rad)
   0.4
X3 = headsail camber perpendicular to forestay at clew
   0.07
X4 = twist headsail in (rad)
   0.58
X3MIN = bound for minimal value of X3, default = 100
   0.06
X4MIN = bound for minimal value of X4, default = 100
   0.45
```

The parameters `X3MIN` and `X4MIN` are values of the lower bounds for `X3` and `X4`. With these bounds one can limit the search area of the optimizer. This is necessary if an intrusion of the spreader into the headsail must be avoided. The bounds can also serve as a counter measure if the optimizer converges to a local optimum that is unrealistic and most likely not the global optimum. The program also uses upper bounds that depend on the starting values and cannot be changed:

```
X1MAX = X1+0.1                          X2MAX = X2+0.15
X3MAX = X3+0.05                         X4MAX = X4+0.15
```

It is advisable to save the downloaded input file without altering it. It can be used as a template for further input files in the future. Additional empty lines between the lines with input are not allowed.

4 RUNNING THE PROGRAM

When opening UliSail.exe the following window will appear and will ask you for the identifier of the input file (depending on the setting of your command prompt options, the background color might be black). Here in the example the identifier for the file was "d33". The

```
C:\Users\Uli\Desktop\UliSail\UliSail_3.5\UliSail_3.5.exe
***************************************************
*                 UliSail 3.5                      *
*      Copyright (C) 2024 Ulrich Remmlinger        *
*     This is research code, commercial usage      *
*         and distribution not allowed.            *
*      You run this program at your own risk       *
* The author accepts no warranty and no liability *
*      For more details see www.remmlinger.com     *
***************************************************

If you agree to the above conditions,
type 3 characters ### and press ENTER
input file INPUT/USL_###_in.TXT will be used
d33
    X1         X2         X3         X4          Phi       Fdrive    F-merit  spike
 0.000000  0.400000  0.070000  0.580000   20.1245    389.15    320.37   2  new best value
 0.000000  0.400000  0.070000  0.580000   20.1245    389.15    320.37   2

Do you want to optimize the trim parameters? Type Yes or No
y
```

program will use the initial parameters `X1-X4` and solve the equations for the equilibrium of forces and moments. The result is printed in one line. `X1`, `X2` and `X4` are displayed in radians. `Phi` is the heel angle, `Fdrive` is the driving force in neg. *x*-direction and `F-merit` is a figure of merit that is gained from `Fdrive` by subtracting a penalty for spikes and the wavi-ness of the induced velocities. The last figure in the line is the number of spikes. The solution is usually not unique. There might be several possible solutions for a given set of the parameters `X1-X4`. The algorithm tries to find a higher figure of merit for the same parameters and prints the result in the second line. If the code dos not find a converged solution, it is often

```
C:\Users\Uli\Desktop\UliSail\UliSail_3.5\UliSail_3.5.exe
 0.040009  0.375273  0.071570  0.560307   18.2813    399.94    397.58   0
 0.040004  0.375273  0.071570  0.560299   18.5744    396.44    311.85   2
 0.040014  0.375273  0.071570  0.560299   18.2813    399.94    397.57   0
 0.040009  0.375270  0.071570  0.560299   18.5743    396.44    311.85   2
 0.040009  0.375277  0.071570  0.560299   18.2813    399.94    397.58   0
 0.040009  0.375273  0.071570  0.560299   18.5742    396.44    311.85   2
 0.040009  0.375273  0.071571  0.560299   18.2813    399.94    397.58   0
 0.040009  0.375273  0.071570  0.560296   18.5741    396.44    311.84   2
 0.040009  0.375273  0.071570  0.560303   18.2813    399.94    397.58   0
 0.040009  0.370273  0.071570  0.560299   18.7115    396.98    313.81   2
 0.040009  0.374773  0.071570  0.560299   18.5878    396.50    312.06   2
 0.040009  0.380273  0.071570  0.560299   18.2813    397.89    395.72   0
 0.040009  0.375273  0.066570  0.560299         shroud cuts into jib-foot
 0.040009  0.375273  0.071070  0.560299   18.5725    396.69    312.82   2
 0.040009  0.375273  0.076570  0.560299   18.2813 residual error too large
 0.040009  0.375273  0.072070  0.560299   18.2813 residual error too large
 0.040009  0.375273  0.071570  0.555299   18.5579    397.03    312.33   2
 0.040009  0.375273  0.071570  0.565299   18.2813 residual error too large
 0.040009  0.375173  0.071570  0.560299   18.5769    396.45    311.89   2
 0.040009  0.375223  0.071570  0.560299   18.5755    396.45    311.87   2
 0.040009  0.375248  0.071570  0.560299   18.5748    396.45    311.85   2
 0.040009  0.375261  0.071570  0.560299   18.5745    396.45    311.85   2
 0.040009  0.375267  0.071570  0.560299   18.5743    396.44    311.85   2
 0.040009  0.375270  0.071570  0.560299   18.5742    396.44    311.85   2
 0.040009  0.375272  0.071570  0.560299   18.5742    396.44    311.84   2
 0.040009  0.375273  0.071570  0.560299   18.5742    396.44    311.84   2

Phi =   18.2812944074001
F_merit =   397.576552889689
F_drive =   399.939505425501
Fx_aero =   515.643629037472
Fy_aero =   2109.36537528425
Heelmom =   15772.5172123137
Ispike =           0
PENALTY=  2.854605144439682E-003
Delta used  =   3.80000000000000
Delta likely=   3.59758768367763

IFFCO found this optimum:
X1 =   4.000905284306919E-002
X2 =   0.375273437500000
X3 =   7.157031250000001E-002
X4 =   0.560299232642819
IFFCO used          411  function evaluations.
press Enter to quit
```

sufficient to alter the starting values only slightly. If there are too many spikes, it often helps, to increase the sheeting angles. At large true wind angles (> 90°) spikes cannot be avoided. If you have a converged solution, you can select, whether you want to optimize the trim parameters or use the current result. In case of optimization, the code will maximize the figure of merit. The screenshot at the end of the run is depicted on page 7. The result is the optimal flying shape of the sails. The shape is for the stretched sails under load. Each line shows the parameters `X1-X4` that were proposed by the optimizer IFFCO and the results `Phi`, `Fdrive` and `F-merit`. The printed results for the optimum at the end are `Fx_aero` and `Fy_aero`, which are the sail-forces in -*x*- and *y*-direction. The driving force `Fdrive` is equal to `Fx_aero` minus the amount of the induced resistance at the keel that is caused by the generation of the side force. The trim parameters at the optimum are listed at the end.

5 THE OUTPUT FILES

There are three files in the folder USL. The file `OUT_d33.TXT` repeats the results that were printed on the screen. The file `Vi_d33.TXT` contains a listing of the induced velocities u_i and w_i for the 31 panels of the headsail and the 31 panels of the mainsail. It should be checked for spikes and waviness. In the file `Coeff_d33.TXT` one can find the coefficients and aerodynamic characteristics as a function of the height in *z*-direction. This distribution gives an insight into the flow around the sails. The listed sheeting angles as a function of *z* are measured at a right angle to the mast for the mainsail and at a right angle to the forestay for the headsail. The camber is measured along the chord in the direction of the apparent wind. There is also a description of the apparent wind (angle and speed) as a function of *z*. Excel can read the text-files and one can use the data to create diagrams that explain the flow. The file `D33.xlsx` shows possible interpretations. These excel-diagrams should always be created because the program is not a foolproof tool that can be trusted blindly. It requires the knowledge of an aerodynamicist to interpret the results. The description of the theory in [1] points to possible failures and weaknesses. The additional files are scripts for the CAD-program.

It should also be kept in mind, that the 2D-coefficients that are used for the computation were determined with XFOIL [3] for ideal conditions. In real life, the sails will have wrinkles and the profile will not exactly follow the optimal shape. Small disturbances at the surface can already lead to local flow separation. The driving force will be smaller than the computed value.

The next step in my work is the combination of UliTank and UliSail, which will lead to the velocity prediction program (VPP) UliSpeed. Results show, that the heel angle determined by UliSail differs from the value in UliSpeed. The root cause is the simple model for the righting arm in UliSail. In UliSpeed, the true form of the hull is used for the heeled attitude in a hydrostatic calculation. UliSail uses the Delft-method for the calculation of the induced resistance. This is also crude, compared to UliSpeed.

When I developed the program, my emphasis was on speed and simplicity, not on nice graphics. Without a graphical interface, it might be tedious to create the input file for the first time, but it saves a lot of time afterwards, when you only want to test small changes.

6 3D-SURFACES in CAD

You can use the CAD-programs RHINO or DELFTSHIP to create 3D-surfaces of the flying shapes of the sails, that were determined by UliSail. You must specify the CAD-program at the end of the input file. The next steps are:

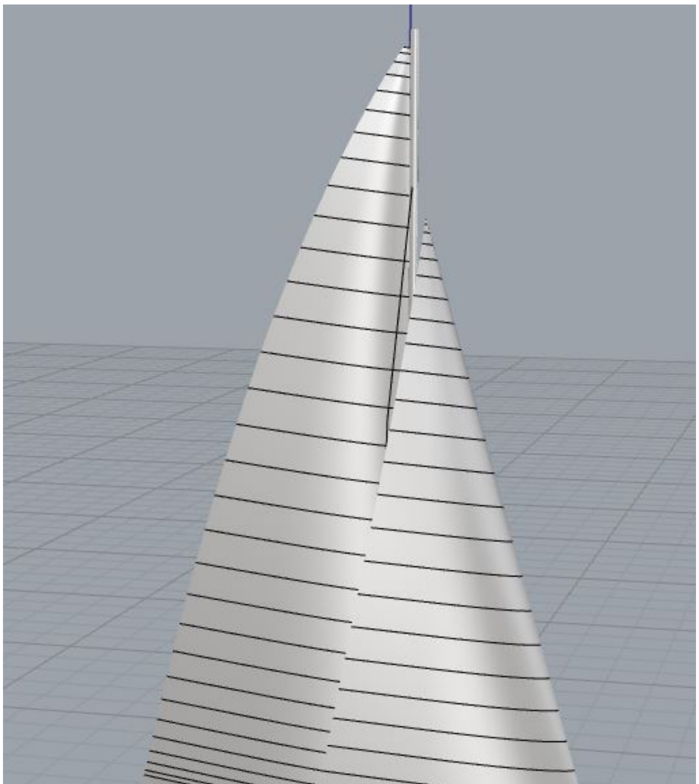
6.1 Creating the surfaces in RHINO

From the Menu in Rhino use Tools > Commands > read from file > go to "MAIN_d33.txt" in the folder USL and open it. It will take some time until all curves are read. You have to wait until the "loft options dialog box" opens. Leave the surface as it is and click on OK. Go to the layer-list and name the layer "MAIN". Create a new layer and name it "JIB". Make this the active layer and switch off the layer "MAIN". Go again to Tools > Commands > read from file > go to the file "JIB_d33.txt" and open it. Accept the lofted surfaces by clicking OK. At last, you should create the new layer "MAST", make it active and switch off all other layers. Then > read from file > go to the file "MAST_d33.txt". You can now switch on all layers and you will see all sails in their correct position. The menu-point render provides shaded views.

6.2 Creating the surfaces in DELFTSHIP

Go to Load > Import > Surface and go to the file "MAIN_d33.txt" in the folder USL and open it. The lofted surface will be displayed. Go to "Save As" and select "Part". Open in the same way the file "JIB_d33.txt" and save the created surface also as a .part-file. The two .part-files can now be loaded into DELFTSHIP and can be viewed together. The mast is not available.

The following pictures are screen shots of the example Dehler 33 at a true wind angle of 41° and a wind speed of 10 knots. The CAD-Program is Rhino5. The sails are shown in the coordinate system of the boat; the origin is at the goose-neck. The water-plane would be inclined to the mast by the heel-angle. The lines on the sails are sections in the direction of the stream-lines. The IGES-file is in the downloaded folder.



Good luck with your computations. Feedback reaches me at ulrich@remmlinger.com

7 REFERENCES

1 Remmlinger, U. "Calculating Aerodynamic Forces for Bermuda Sail Plans", [Online], Available:http://www.remmlinger.com/3D%20Aerodynamics.pdf

2 Gerritsma, J., Onnink, R., Versluis, A., "Geometry, Resistance and Stability of the Delft Systematic Yacht Hull Series", *Int. Shipbuilding Progress*, Vol. 28, Nr. 328, pp. 276-297, 1981

3 Remmlinger, U., "Aerodynamic Characteristics of 2D Sail Sections ", [Online]. Available: http://www.remmlinger.com/2D%20aerodynamics.pdf