A Quick Guide to FreeWake20

A more detailed description of the underlying theoretical model with validation and sample applications is listed in "A Higher Order Vortex-Lattice Method with a Force-Free Wake," by Götz Bramesfeld, Dissertation, Pennsylvania State University, August 2006.

FreeWake2020 is a modification of FreeWake2007/2008/2018/2019. FreeWake20

- has different input and output structures compared to the older versions,
- can model camber lines
- can model junctions with more than two lifting surfaces intersecting (e.g. T-tail)
- can deflect trailing edge flaps
- can trim (pitch and roll so far)
- do alpha and CL based calculations
- model turning flight.
- The flightpath can be in the horizontal plane or descending along alpha

It is meant to work integrated with Vogen.

The program computes the inviscid loads of up to five wings (maybe more). It uses two wake models, one that is prescribed and based on Horstmann's multiple lifting line method and one that uses a relaxed, force-free wake model. Either model has lifting lines with a spanwise circulation distribution of the shape of a second-order spline.

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How to compile

- g++ Source/Main_PerfCode2020.cpp -o fw
- the executable is “fw”

Directory Structure

FreeWake20 requires several subdirectories in order to run properly. The input directories (inputs, camber, and airfoils) have to be created by user before running.

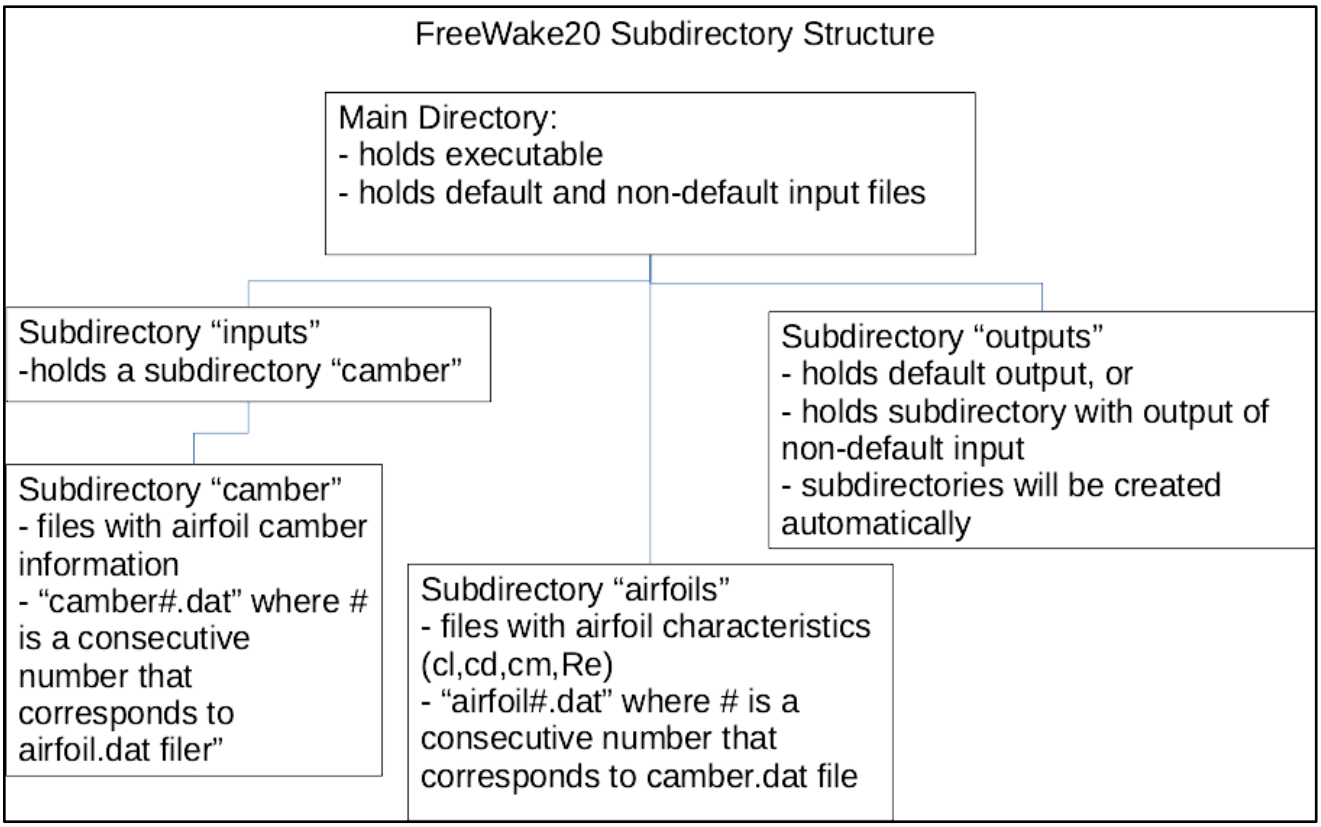

Figure 1: Subdirectory structure of FreeWake20.

Inputs

The default input file is a text file named “input.txt” that is located in the same directory as the executable. The output is written to /output.

A non-default input file is used, e.g. WingC.txt, by calling the program with the executable followed by the root of the non-default input file, e.g. ./fw WingC. The program will create the output subdirectory that has the root of the non-default input file name, e.g. /output/Wing/.

Input Files

- The lifting surface geometry and flow conditions are defined in the input file
- Unless a camber line is defined (in /input/camber/) each lifting surface defines the zero-lift plane of the wing that is modelled, similar to a vortex lattice method. Up to five wings can be defined. Each wing consists of one or more panels. Each panel has the same number of chordwise separations (parameter m). The number of spanwise elements can be defined individually for each panel (parameter n). Subsequently, each panel has of mxn elements.
- Camber files hold the camber lines. The camber files are located in the subdirectory inputs/camber and are named camber#.camb, with # being consecutive numbers starting at 1. Camber files are only needed if camber = 1 in input file.
- Airfoil files hold aerodynamic characteristics of different airfoils (AoA, cl, cd, Re, cm). The files are in the subdirectory airfoils/. The files are named airfoil#.dat, with # being consecutive numbers starting at 1. Airfoil files are only needed if viscous = 1 in input file. Note, the viscous model might be out of order (Jan. 2021)
- The following signs serve as identifiers in the input files and, thus, should be used carefully: '= ', ':' and '#'. Any further spaces or comments are being ignored.

Geometry and Configuration Input File

- Holds configuration and general information.
- Should be in directory of executable.
- The sample input file models the wing and t-tail configuration of Fig. 2.

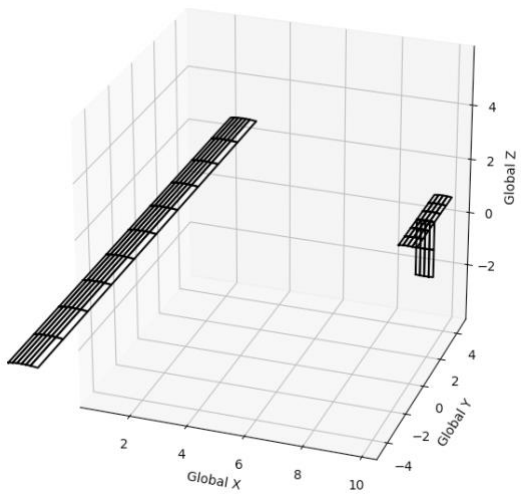

Figure 2: Wing-tail configuration of sample input file.

As indicated in Fig. 2, the coordinates system is positive x in wind direction, positive y along right wing and positive z up.

In the input file, the leading-edge lines are defined for the left and right panel edges (looking in direction of flight) as is the chord and the incidence angle (positive epsilon = pitch up) of the respective edges. Thus, twist can be introduced having different epsilons on either side edge of that particular panel or by using different camber lines at left and right edge. When camber=1, the wing is modeled as a flat-plate and twist is only possible through defining changing incidence angles (epsilon). Therefore, epsilon should align the panel with the zero-lift line of the particular wing section.

'Bound.Cond.' defines the boundary conditions at the respective edge of the panel. For example, the boundary condition of a wingtip is '100', which stands for zero circulation, unknown vorticity strength and derivative thereof. The value '220' is used for two or more neighboring elements (equal circulation and vorticity) and '010' along the symmetry plane (unknown circulation, zero vorticity, unknown vorticity gradient).

Next, a sample input file with explanations. It is the file that was used to model the configuration in Fig. 2.

BEGINNING OF SAMPLE INPUT FILE (comments in red)

General comments, can be of any length.
Please note that the program uses equal, number and : signs as special recognizers!
The results are written to the sub-directory output'

Simulation parameters
Relaxed wake (yes 1, no 0): relax = 0 choice of wake model
Steady (1) or unsteady (2): aerodynamics = 1 =2 Quasi unsteady I (no apparent mass)
Viscous solutions (1) or inviscid (0) viscous = 0 =1 to estimate profile drag, airfoil files have to exist (may not work)
Using camber (1) or no camber (0) camber = 1 =1 than camber files have to exist (Fig. 1)
Symmetrical geometry (yes 1, no 0): sym = 0 =1 only right wing is modeled (may not work)
Pitch trim (yes 1, no 0): trimPITCH = 0 trim flags
Roll trim (yes 1, no 0): trimROLL = 0
Lift trim (yes 1, no 0): trimCL = 1 =1 will iterate to match target CL,
CL = 2W cos(phi)/{density Uinf^2 S}

Max. number of time steps: maxtime = 20 number of timesteps
Width of each time step (sec): deltime = .5 Defines timestep size (with Uinf)
Convergence delta-span efficiency: deltae = 0.00 (0 if only timestepping) convergence criteria
freestream flow condition
Freestream velocity: Uinf = 10
AOA beginning, end, step size [deg]: alpha= 5 15 1 ignored if trimCL= 1 than alpha sweep: 5 to 15 deg every 1deg
Sideslip angle [deg]: beta = 0 (nonzero may not work)
Turning flight conditions
Circling flight information
Circling flight on (1) off (0): circling = 0
Turning in horizontal plane (1) horizontal = 0 if (0), a/c descends
Bank angle (deg) phi = 20 bank angle
Upwind velocity (m/s) Ws = 0 if there is a vertical velocity, leave at zero, may not work
Velocity gradient (1/s) gradient = .3864 radial velocity gradient when turning.
If set to gradient=0 => gradient = (9.81 * tan(info.bank)) / (info.Uinf)

Density: density = 1.225 used to compute CL if Lift trim is turned on
Kinematic viscosity: nu = 1.420000e-05 needed to get chord-Reynolds number when viscous model is on

Reference area: S = 20
Reference span: b = 20

Mean aerodynamic chord: cmac = 1
Aircraft weight (N): W = 3000.0
CG location (x y z): cg = 0.25 0 0 cg location (x,y,z)
CMo of wing: CMo = 0.000 additional CM, obsolete

No. of wings (max. 5): wings = 2 a t-tail is a single wing
No. of panels: panels = 5 total number of panels. Several panels define a wing
No. of airfoils (max. 15): airfoils = 2 defines how many camber and/or airfoil files need to be provided
general review of some parameters
Panel boundary conditions:
Symmetry line - 10
Between panels - 220
Free end - 100

Hinge is in percentage chord:
Midchord - 0.5
Leading edge - 0
NO HINGE - 1

Defines leading edge of wing, all measured in metres:
Definition of panels that describe the geometry. Each panel has nxm DVEs in the spanswise and chordwise direction, respectively. Each panel can have unique n and m values. If neighboring panels have different m-values, this may result in discontinuous circulation distribution. “overhanging” lifting lines are treated like wingtips (BC =100)
Left wing panel. The information of the first panel, panel 1, starts here:
Panel #:1. Number of elements across span n = 5 and chord m = 6
Neighbouring panels (0 for none) left: 0 right: 2 panel at the right and left of panel. If 0 than no neighbouring panel. If more than one neighboring element, listing one is sufficient.

left edge information: x,y,z, chord length, incidence angle, bound. Cond., airfoil (camber, airfoil), hinge location/deflection. Airfoil and camber can change across a panel. Program interpolates value based on the edge parameters. Hinge lines can be swept. Flap deflections have to be constant across a panel.
xleft yleft zleft chord epsilon Bound.Cond. Airfoil Hinge Deflection
0.0 -10 0.00 1.00 0.00 100 6 0.75 0
xright yright zright chord epsilon Bound.Cond. Airfoil Hinge Deflection
0.0 0 0.000 1. 0.000 220 6 0.75 0
right wing panel
Panel #:2. Number of elements across span n = 5 and chord m = 6
Neighbouring panels (0 for none) left: 1 right: 3
xleft yleft zleft chord epsilon Bound.Cond. Airfoil Hinge Deflection
0.0 0 0.00 1.00 0.00 220 6 0.75 0
xright yright zright chord epsilon Bound.Cond. Airfoil Hinge Deflection
0.0 10 0.000 1. 0.000 100 6 0.75 0
left horizontal tail panel (its right edge borders panels 4 and 5).
Panel #:3. Number of elements across span n = 3 and chord m = 4
Neighbouring panels (0 for none) left: 0 right: 4
xleft yleft zleft chord epsilon Bound.Cond. Airfoil Hinge Deflection
10.15 -2.00 2.00 0.600 .00 100 6 0.75 0
xleft yleft zleft chord epsilon Bound.Cond. Airfoil Hinge Deflection
10.15 .00 2.00 0.600 .00 220 6 0.75 0
right horizontal tail panel (its left edge borders panels 3 and 5)
Panel #:4. Number of elements across span n = 3 and chord m = 4
Neighbouring panels (0 for none) left: 3 right: 0
xleft yleft zleft chord epsilon Bound.Cond. Airfoil Hinge Deflection
10.15 .00 2.00 0.600 .00 220 6 0.75 0
xleft yleft zleft chord epsilon Bound.Cond. Airfoil Hinge Deflection
10.15 2.00 2.00 0.600 .00 100 6 0.75 0
vertical tail panel. Note, it borders right of panel 3 and left of panel 4
Panel #:5. Number of elements across span n = 2 and chord m = 4
Neighbouring panels (0 for none) left: 0 right: 4
xleft yleft zleft chord epsilon Bound.Cond. Airfoil Hinge Deflection
10.15 .00 .00 0.600 .00 100 6 0.75 0
xleft yleft zleft chord epsilon Bound.Cond. Airfoil Hinge Deflection
10.15 .00 2.00 0.600 .00 220 6 0.75 0

old definitions related to fuselage and empennage drag, obsolete but can be reactivated.
%<- special identifier
Vertical tail information:
Number of panels (max 5) = 0

no. chord area airfoil

Fuselage information:
Number of sections (max 20) = 0
Width of each section = 0.000
Panel where transition occurs = 0
No. Diamter

Interference drag = 0.0%
##############

END OF SAMPLE INPUT FILE

Camber File

- Needed when camber =1 in geometry and configuration file.
- Defines camber line. File name is inputs/camber/camber#.camb where # is a consecutive number that starts at 1.
- Number in name should correspond to airfoil file if viscous solution is calculated
- Aerodynamic twist is possible, that is change in camber lines across the span of a panel.
- First line is a comment; two columns: x and y_camber. From leading edge to trailing edge.
- Leading and trailing edges (x = 1 and 0, respectively) have to be defined.
- Can be generated using xfoil.

BEGINNING OF SAMPLE CAMBER LINE FILE

```
camber1.camb generated by VoGen
 0.000000  0.000000
 0.004487  0.002682
 0.007486  0.003763
 0.015020  0.006025
 0.017521  0.006688
 0.030965  0.009840
 0.049894  0.013555
.
.
.
.
0.954077  0.006379
 0.969592  0.004359
 0.973991  0.003769
 0.986350  0.002055
 0.988387  0.001764
 0.996558  0.000548
1.0000 0.00
```

END OF SAMPLE CAMBER LINE FILE

Airfoil File

- Needed when viscous =1 in geometry and configuration file.
- Holds section characteristics of airfoils. File name is airfoils/airfoil#.dat where where # is a consecutive number that starts at 1.
- Number in name should correspond to camber file if camber line is used (camber = 1)
- Change in airfoil across panel possible.
- First line is a comment; five columns: alpha, cl, cd, Re, cm.
- For each Reynolds number sorted from minimum cl to maximum cl. cl has to increase, i.e. no post stall data. Reynolds number blocks sorted from lowest chord- Reynolds number to highest.
- Program uses a linear interpolation between points, thus density can be limited in low drag regions.
- Can be generated using xfoil, experiments, cfd.

BEGINNING OF SAMPLE AIRFOIL FILE

```
FX 67-K-170/17     0 degrees Flap    Number of Rows =374        Number of rows of data
        -5      0.0084 0.01632      5.00E+05     -0.107
        -4.8    0.028   0.01571     5.00E+05     -0.1067
        -4.6    0.0476 0.01518      5.00E+05     -0.1064
        .
        .
        .
        .
        8.2     1.3708 0.01158      5.00E+05     -0.104
        8.4     1.3776 0.01174      5.00E+05     -0.1016
        8.6     1.3779 0.01215      5.00E+05     -0.0983      Next Reynolds number
        -5      0.0097 0.01398      7.00E+05     -0.1065
        -4.8    0.0293 0.01344      7.00E+05     -0.1062
        -4.6    0.0491 0.01299      7.00E+05     -0.1059
        .
        .
        .
        7.8     1.3455 0.00982      7.00E+05     -0.1061
        8       1.3502 0.00996      7.00E+05     -0.103
        8.25    1.3515 0.01024      7.00E+05     -0.0984      Next Reynolds number
        -5      0.0086 0.01222      1.00E+06     -0.1059
        -4.8    0.0286 0.01179      1.00E+06     -0.1056
        -4.6    0.0489 0.0114       1.00E+06     -0.1055
        .
```

```
.
.
7       1.3039 0.00828      1.00E+06    -0.1141
7.2     1.3195 0.00843      1.00E+06    -0.1132
7.4     1.3343 0.00855      1.00E+06    -0.1121
7.8     1.3499 0.00904      1.00E+06    -0.1073      Next Reynolds number
-5      0.0002 0.00781      4.00E+06    -0.1044
-4.8    0.0224 0.0077       4.00E+06    -0.1046
.
.
.
6       1.2294 0.00591      4.00E+06    -0.1202
6.2     1.2404 0.00636      4.00E+06    -0.1185
6.4     1.2463 0.00695      4.00E+06    -0.1158
6.6     1.2465 0.00762      4.00E+06    -0.112
END OF SAMPLE AIRFOIL FILE
```

Output

- Several output files are being produced and written to files the 'output' directory. The default output directory is output/. If the configuration input file has been specified when running the FW20 (e.g. /fw Input), the outputs are stored in the directory output/input/.
- In any case a geometry check file will be generated in the main directory (for default and specified inputs) and can be plotted using Python: "python geometryCheck.py"
- The output files are (assuming configuration file was input.txt):
    - Input.txt: mirror of original configuration file
    - TrimSol.txt and Performance.txt: old leftovers from FW18 and older and not maintained.
    - input_cfg.txt: holds summary of the particular flight conditions, that is, alpha or CL.
    - input_FC#1.txt: holds spanwise load distribution of the 1st flight condition. Subsequently numbered files hold similar load distributions for other flight conditions. Numbers correspond with flight condition number in input_cfg.txt.
    - input_TDVE#1.txt: holds information of surface and wake DVEs after completion of calculation of 1st flight condition. Subsequently numbered files hold similar load distributions for other flight conditions. Numbers correspond with flight condition number in input_cfg.txt.
    - input_SDVE#1.txt: holds information of surface DVEs after completion of calculation of 1st flight condition. Subsequently numbered files hold similar load distributions for other flight conditions. Numbers correspond with flight condition number in input_cfg.txt.
    - VoGen.txt: holds a summary of load coefficients of last run case. Used to interact with trim routine for moments in VoGen.

Some general header information:

Chord: chord length of element

eta: halfspan of element

phi: sweep angle

nu: dihedral angle

epsilon: incidence angle

psi: yaw angle