AERSP 597B
Wind Turbine Aerodynamics

"XTurb-PSU"

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Last Updated : June 8th 2011

User’s Guide

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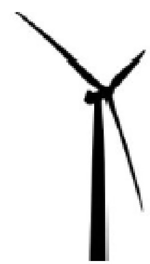
XTurb-PSU



A WIND TURBINE Design & Analysis Tool

Developed at The Pennsylvania State University

Objectives

- Getting Started
- Input Modules
  - Blade (Geometric Definitions)
  - Operation (Design, Analysis, Prediction)
  - Solver (Solver & Grid Selection)
  - HVM (Helicoidal Vortex Method)
  - BEMT (Blade Element Momentum Theory)
- Output Files
  - General & Method Specific Output

Getting Started

- Extract Files from XTurb-PSU_V#.#.tar

```
tar -xvf  XTurb-PSU_V#.#.tar
```

- Run Directory

```
cd XTurb-PSU_V#.#
mkdir test1
cd test1
cp ../Example_1/ex1.inp  ./test1.inp
```

- Executable

```
../src/XTurb-PSU-g95**.exe < test1.inp
```

Getting Started

- Executable

```
You can also use … 'nohup'

/usr/bin/nohup ../src/XTurb-PSU-g95**.exe < test1.inp > nohup.out

This will re-direct all screen output to nohup.out.
```

- Operating Systems
  - Unix/Linux
  - Windows + Cygwin (recommended)
  - Windows Command Prompt (?)

Input Modules

- Structure of Input File

`&BLADE` … `&END`	**Geometric Definitions**
`&OPERATION` … `&END`	**Design, Analysis, Prediction**
`&SOLVER` … `&END`	**Solver & Grid Selection**
`&HVM` … `&END`	**Helicoidal Vortex Method**
`&BEMT` … `&END`	**Blade Element Momentum Theory**

Input Modules

- Inputs - BLADE

&BLADE		
Name	= 'NREL-PhaseVI',	**Design Name**
BN	= 2,	**Blade Number**
ROOT	= 0.25,	**Root Location / Radius**
NTAPER	= 2,	**# Chord Definitions**
RTAPER	= 0.25, 1.00,	**Radial Location / Radius**
CTAPER	= 0.1465, 0.0707,	**Blade Chord / Radius**
&END		

Input Modules

- Inputs - BLADE

```
&BLADE
   NTWIST     = 20,            # Twist Definitions

   RTWIST     = 0.250,         Radial Location / Radius
                0.267,
                  …
                1.000,

    DTWIST    = 20.040,        Twist Angle [deg]
                18.074,
                  …
                -1.816,

     NAIRF    = 2,             # Airfoil Polars
&END
```

Input Modules

- Inputs - BLADE

```
&BLADE
   RAIRF    = 0.25,                 Radial Location / Radius
              0.50,

   AIRFDATA = './S809_Re6E5.dat',   Path to XFOIL Polar
              './S809_Re1E6.dat',

     NSWEEP   = 2,                  # Sweep Definitions

     RSWEEP   = 0.25,               Radial Location / Radius
                1.00,

     LSWEEP   = 0.00,               Blade Sweep / Radius
                0.00,
&END
```

Input Modules

- Inputs - BLADE

Example : XFOIL Polar

```
      XFOIL         Version 6.8

 Calculated polar for: 1.     0.

 1 1 Reynolds number fixed          Mach number fixed

 xtrf =   1.000 (top)        1.000 (bottom)
 Mach =   0.000     Re =     0.500 e 6     Ncrit =   9.000

   alpha     CL        CD       CDp       CM     Top Xtr  Bot Xtr
  ------- -------- --------- --------- -------- -------- --------
   0.000   0.1452   0.01352   0.00682  -0.0431   0.6141   0.5406
   0.500   0.2046   0.01361   0.00689  -0.0447   0.6125   0.5425
   1.000   0.2633   0.01357   0.00696  -0.0461   0.6108   0.5449
   1.500   0.3223   0.01364   0.00715  -0.0474   0.6093   0.5471
       …              …              …              …
```

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Input Modules

- Inputs - BLADE

```
&BLADE
      NDIHED   = 2,        # Dihedral Definitions
      RDIHED   = 0.25,     Radial Location / Radius
                 1.00,

      LDIHED   = 0.00,     Blade Dihedral / Radius
                 0.00,

      NTWAX    = 2,        # Twist Axis Definitions

      RTWAX    = 0.25,     Radial Location / Radius
                 1.00,

      LTWAX    = 0.30,     Twist Axis / Chord
                 0.30,
&END
```

Input Modules

- Inputs - BLADE

```
&BLADE
      NPIAX    = 2,          # Pitch Axis Definitions
      RPIAX    = 0.25,       Radial Location / Radius
                 1.00,

      LPIAX    = 0.30,       Pitch Axis / Chord
                 0.30,
&END
```

Note that in current version …

1. No Sweep & Dihedral (BEMT); No Dihedral (HVM)
2. No usage of NTWAX, RTWAX, LTWAX and NPIAX, RPIAX, LPIAX

Input Modules

- Structure of Input File

&BLADE ... &END	Geometric Definitions
&OPERATION ... &END	Design, Analysis, Prediction
&SOLVER ... &END	Solver & Grid Selection
&HVM ... &END	Helicoidal Vortex Method
&BEMT ... &END	Blade Element Momentum Theory

Input Modules

- Inputs - OPERATION

```
&OPERATION
     CHECK    = 1,
&END
```

The CHECK Setting …

```
CHECK    = 1,
```

- Recommended before actual computation
- Review input parameters and solver settings

```
CHECK    = 0,
```

- Proceeds directly to computation

Input Modules

- The CHECK Setting (What to look for …)

```
**************************************************
*                 AIRFOIL DATA                   *
**************************************************

***** Airfoil Polars  NAIRF       =  2  *****

*** Polar # 1 ***
  r/R     File
  0.2500 ./S809_Re6E5.dat

  From     To       (r/R)
  0.2500   0.500

+++++ Extrema of Cl vs. alpha +++++

     Extremum = 29  CL = 1.0733
     Extremum = 31  CL = 1.0709
     Extremum = 39  CL = 1.0958

 Number AOA[deg] CL       CD       CDP      CM
---------------------------------------------------
    1   0.0000   0.1452   0.0135   0.0068  -0.0431
    2   0.5000   0.2046   0.0136   0.0069  -0.0447
    3   1.0000   0.2633   0.0136   0.0070  -0.0461
          …         …         …         …         …
```

Input Modules

- The CHECK Setting (What could happen …)

```
+++++ Extrema of Cl vs. alpha +++++

     Extremum = 29  CL = 1.0733
     Extremum = 31  CL = 1.0709
     Extremum = 39  CL = 1.0958
     Extremum = 51  CL = 1.53493285
     Extremum = 55  CL = -1.43988514
     Extremum = 59  CL = 1.30977213

Data Distribution NOT favorable !
Curvature change in CD vs. CL at single data point
 Suggest adding/interpolating a new data point
 ... between 52 and 53 i.e. AOA = 0.275000006 deg and AOA =
0.349999994 deg

Data Distribution NOT favorable !
Curvature change in CD vs. CL at single data point
 Suggest adding/interpolating a new data point
 ... between 58 and 59 i.e. AOA = 0.725000024 deg and AOA =
0.800000012 deg

 Number AOA[deg] CL        CD        CDP       CM
---------------------------------------------------
    1   0.0000   0.1452    0.0135    0.0068   -0.0431
    2   0.5000   0.2046    0.0136    0.0069   -0.0447
        …        …         …         …         …
```

If you repair the polar file manually, you get the OK as on the previous slide.

Input Modules

- The CHECK Setting (What to look for …)

```
***************************************************
*            RADIAL DISTRIBUTION - INPUT            *
***************************************************

Using a COSINE distribution from root to tip ...

Input Data interpolated to radial stations r(j)

 Number r/R     Chord/R Twist[deg] Sweep/R  Dihed/R  Polar #
-------------------------------------------------------------
    1   0.2500   0.1465  20.0400   0.0000   0.0000     1
    2   0.2512   0.1464  19.9063   0.0000   0.0000     1
    3   0.2546   0.1460  19.5061   0.0000   0.0000     1
    4   0.2604   0.1455  18.8417   0.0000   0.0000     1
    5   0.2684   0.1446  17.9188   0.0000   0.0000     1
    6   0.2785   0.1436  16.7509   0.0000   0.0000     1
        …        …        …        …        …        …
```

Check that inputs transfer to computational grid

Input Modules

- Inputs - OPERATION

```
&OPERATION
     DESIGN    = 1,
     NTSR      = 10,
     BTSR      = 2,
     ETSR      = 20,
     NPITCH    = 2,
     BPITCH    = 1.8,
     EPITCH    = 3.0,
&END
```

“Design” Mode

 # Tip Speed Ratios, TSR
Minimum TSR
Maximum TSR

 # Blade Pitch Angles
Minimum Pitch Angle [deg]
Maximum Pitch Angle [deg]

Input Modules

- Inputs - OPERATION - Design (Screen Output)

```
Total of NTSR * NPITCH = 20 cases.

 +++++++ The following cases will be computed. +++++++

   Number   TSR       PITCH [deg]
        1   2.0000    1.8000
        2   4.0000    1.8000
        3   6.0000    1.8000
            …         …         …
       11   2.0000    3.0000
       12   4.0000    3.0000
       13   6.0000    3.0000
            …         …         …
 +++++++++++++++++++++++++++++++++++++++++++++++++++++
```

Input Modules

- Inputs - OPERATION

&OPERATION	
ANALYSIS = 1,	**"Analysis" Mode**
NANA = 10,	**# Blade Analysis Cases**
TSRANA = 2,	**Minimum TSR**
4,	**…**
...	**…**
20,	**Maximum TSR**
PITCHANA = 3.0,	**Minimum Pitch Angle [deg]**
3.0,	**…**
...	**…**
3.0,	**Maximum Pitch Angle [deg]**
&END	

Input Modules

- Inputs - OPERATION - Analysis (Screen Output)

```
Total of NANA = 10 cases.

+++++++ The following cases will be computed. +++++++

  Number    TSR        PITCH [deg]
       1    2.0000     3.0000
       2    4.0000     3.0000
       3    6.0000     3.0000
       4    8.0000     3.0000
       5   10.0000     3.0000
       6   12.0000     3.0000
       7   14.0000     3.0000
       8   16.0000     3.0000
       9   18.0000     3.0000
      10   20.0000     3.0000
+++++++++++++++++++++++++++++++++++++++++++++++++++++
```

Input Modules

- Inputs - OPERATION

```
&OPERATION
 PREDICTION = 1,

     BRADIUS  = 5.03,

     RHOAIR   = 1.225,

     MUAIR    = 1.8E-05,


     NPRE     = 2,

&END
```

“Prediction” Mode

Blade Radius [m]

Air Density [kg/m^3]

Air Dynamic Visc. [kg/(m*s)]

 # Prediction Cases

Input Modules

- Inputs - OPERATION

```
&OPERATION

     VWIND    = 5.0,                Wind Speed [m/s]
                7.0,

     RPMPRE   = 72.0,               Rotor RPM
                72.0,

     PITCHPRE = 3.0,                Blade Pitch Angle [deg]
                3.0,
&END
```

Input Modules

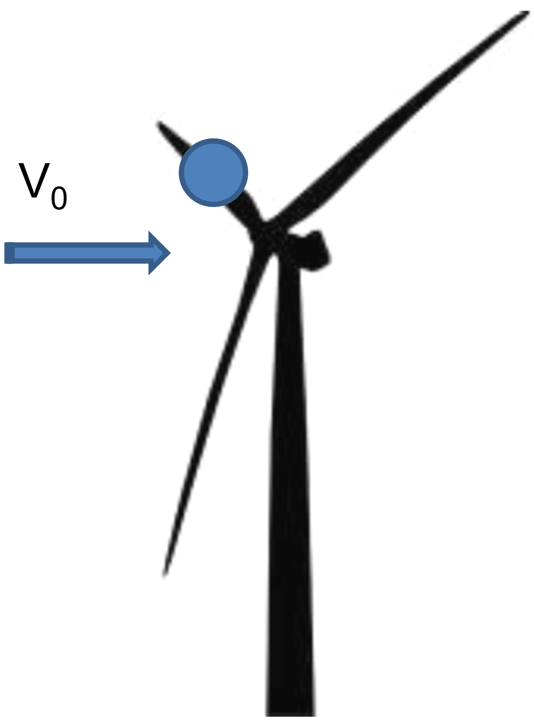
- Inputs - OPERATION - Prediction (Screen Output)

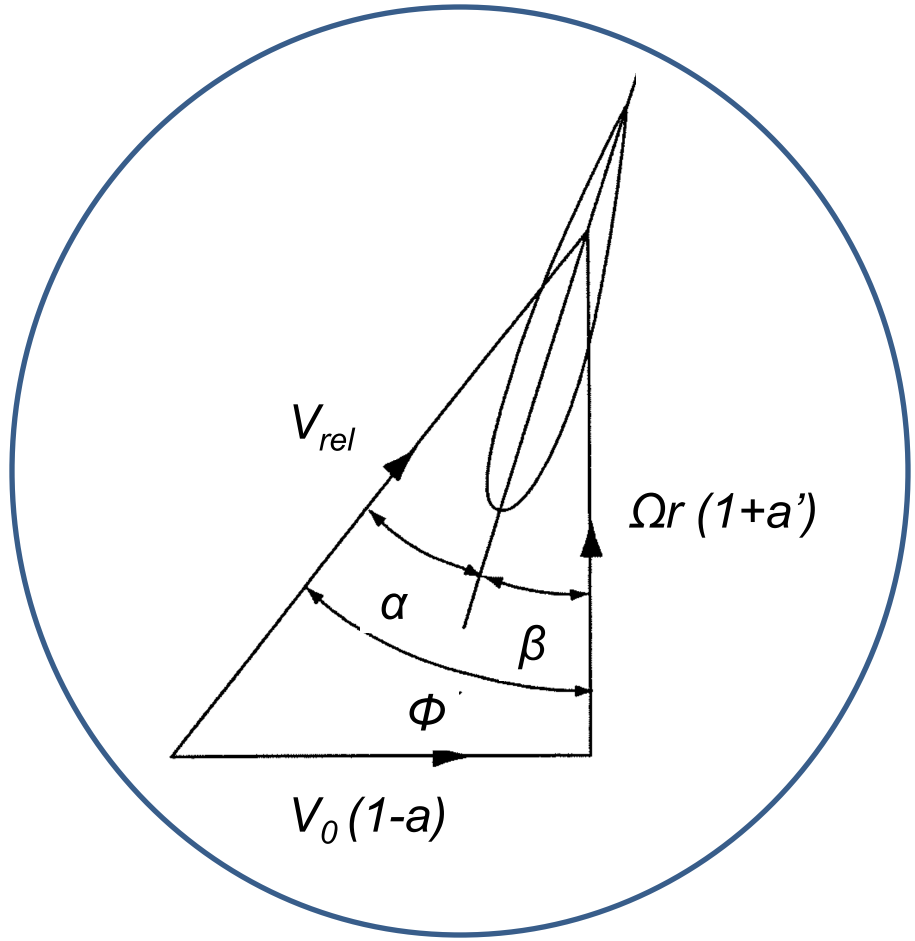
```
Total of NPRE = 2 cases.

 +++++++ The following cases will be computed. +++++++

 Equation :  TSR = (Omega*BRADIUS)/VWIND
                 = (2*pi/60*RPM*BRADIUS)/VWIND

   Number   TSR       PITCH [deg]
        1   7.5851    3.0000
        2   5.4179    3.0000

 +++++++++++++++++++++++++++++++++++++++++++++++++++++
```

XTurb-PSU translates into TSR & PITCH.

Input Modules

- How is PITCH [deg] defined … ?





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Input Modules

- How is PITCH [deg] defined … ?
  - Φ = Local Flow Angle = $\alpha + \beta$
  - α = Local Angle of Attack
  - β = 'Total' Local Twist

    = DTWIST + (PITCH – $DTWIST_{Tip}$)

- Therefore, PITCH = β_{Tip}

Input Modules

- Wind Turbine
  - Positive Twist = Nose Down
  - PITCH = β_{Tip}
- Rotorcraft
  - Positive Twist = Nose Up
  - PITCH = $\beta_{r/R=0.75}$
- The 'Schmitz' Rule says :

"Positive Twist means Nose into the Wind. – Always."

Input Modules

- How is PITCH [deg] defined … ? (Screen Output)

```
**************************************************
*    +++ SOLUTION +++ SOLUTION +++ SOLUTION +++     *
**************************************************

++++++++++ NEW CASE +++++++++++
  Number   TSR       PITCH [deg]
       1   7.5851    3.0000

Non-Dimensionalization :
 Length Scales    => Blade Radius  BRADIUS
 Velocity Scales  => Wind Speed    VWIND

 In other words ... BRADIUS = VWIND = 1.00

Modifying Blade Twist from INPUT :
 Adding 4.816 deg to get Tip Pitch Angle of 3. deg
```

Input Modules

- How is PITCH [deg] defined … ? (Screen Output)

```
 Number    r/R      Twist[deg]
------------------------------
       1   0.2500   24.8560
       2   0.2512   24.7223
             …        …        …
      40   0.9988    3.0079
      41   1.0000    3.0000

Note that Tip Pitch > 0 means ...
   i) Nose Down  or
  ii) Nose into the Wind

  ... this is different from Rotorcraft !
```

Input Modules

- Structure of Input File

&BLADE ... &END	Geometric Definitions
&OPERATION ... &END	Design, Analysis, Prediction
&SOLVER ... &END	Solver & Grid Selection
&HVM ... &END	Helicoidal Vortex Method
&BEMT ... &END	Blade Element Momentum Theory

Input Modules

- Inputs - SOLVER

```
&SOLVER
  METHOD    = 2,
    JX      = 41,
   COSDISTR = 1,
 STALLDELAY = 0,
    GNUPLOT = 0,
&END
```

```
  METHOD  =  1,
          =  2,
```

METHOD = 1, **Blade Element Momentum Theory (BEMT)**

= 2, **Helicoidal Vortex Method (HVM)**

```
    JX    =  # Radial Stations (Odd)
```

Input Modules

- Inputs - SOLVER

`COSDISTR = 0,` **Uniform Spacing along Blade Span**

`COSDISTR = 1,` **Uniform Spacing along Blade Span**
- Recommended for both BEMT & HVM

`STALLDELAY = 0,` **NO modification of Airfoil Data**

`STALLDELAY = 1,` **Stall-Delay Model -> 3-D Effects on Airfoil Data**
- Selig & Du (Lift Coefficient)
- Eggers (Drag Coefficient)

⇔ **AirfoilPrep (NREL)**

Input Modules

- Inputs - SOLVER

`GNUPLOT = 0,`	**Default, i.e. No Output Files for gnuplot**	
`GNUPLOT = 1,`	**'Local' (Radial) Output** - Data File - Script File	
`GNUPLOT = 2,`	**'Local' (Radial) & 'Global' Output** - Data File - Script File	

Input Modules

- Structure of Input File

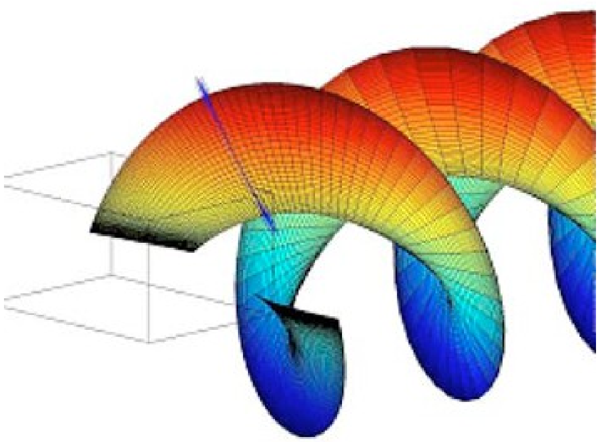
&BLADE ... &END	Geometric Definitions
&OPERATION ... &END	Design, Analysis, Prediction
&SOLVER ... &END	Solver & Grid Selection
&HVM ... &END	Helicoidal Vortex Method
&BEMT ... &END	Blade Element Momentum Theory

Input Modules

- Inputs - HVM

```
&HVM
    WAKEEXP  = 1,
    DX0      = 1.E-04,
    XSTR     = 1.0,
    XTREFFTZ = 20.0,
    NSEC     = 30,
    IB       = 2,
    DIP      = 1,
    OMRELAX  = 0.2,
    AVISC    = 0.0,
    NACMOD   = 0,
    LN       = 0.050,
    HN       = 0.025,
    XN       = 0.000,
&END
```

DEFAULT Settings
No need to change !



Input Modules

- Inputs - HVM (Screen Output)

```
***** HVM *****

 +++++ Vortex Structure - HELIX +++++
         # Filaments jx-1 = 40
 End Mesh Stretching xstr = 1.
             Set xtrefftz = 20.
    Initial Mesh Step dx0 = 0.0001
   Number of Sectors nsec = 30

 +++++ Vortex Structure - BOUND +++++
         # Filaments jx-1 = 40
            # Segments ib = 2
                          = (jx-1)*(ib+1) = 120  Points

 +++++ Vortex Structure - Wake Expans./Contr. +++++
 Wake Expansion/Contraction    WAKEEXP = 0

 +++++ Influence Coefficients +++++
 Interval for Boundary Nodes  DIP = 1
```

Input Modules

- Inputs - HVM (Screen Output)

```
+++++ Solver Parameters +++++
Omega Relaxation Factor  = 0.2
Artificial Viscosity ... = 0.
 ... for separated flow

No Input specified for Nacelle Model !
```

OR (for `NACMOD = 1`)

```
+++ Nacelle Model +++

 Nacelle 1/2 Length (Rankine Body)    LN/R = 0.05
 Nacelle 1/2 Height (Rankine Body)    HN/R = 0.025
 Axial Location of Nacelle midpoint   XN/R = 0.

***** Nacelle Modeling (Rankine Body) *****
```

Input Modules

- Structure of Input File

&BLADE ... &END	**Geometric Definitions**
&OPERATION ... &END	**Design, Analysis, Prediction**
&SOLVER ... &END	**Solver & Grid Selection**
&HVM ... &END	**Helicoidal Vortex Method**
&BEMT ... &END	**Blade Element Momentum Theory**

Input Modules

- Inputs - BEMT

DEFAULT Settings
No need to change !

```
&BEMT
   RLOSS     = 1,
   TLOSS     = 1,
   AXRELAX   = 0.125,
   ATRELAX   = 0.125,
&END
```

Root Loss Factor (AeroDyn)

Tip Loss Factor (AeroDyn)

Relaxation Factor for a

Relaxation Factor for a’

Output Files

- General Output
  - XTurb_Output.dat
  - XTurb_Output1.dat
  - XTurb_Output2.dat
  - XTurb_Output3.dat
- Method Specific Output
  - XTurb_Output_Method.dat
  - <u>For HVM :</u> adv.out, remain.out, bound.out, helix.out, blade_bound.out, blade_helix.out, coeff_coord.out, coeff_bound.out, coeff_helix.out, coeff_nacelle.out

Output Files

- General Output
  - XTurb_Output.dat

```
NREL-PhaseVI                                        ***** XTurb-PSU  -  OUTPUT *****
  Blade Number      BN =  2

  Solidity
  0.0519
                                   + Prescribed Wake Method [Chattot, Schmitz] +

  Number    TSR       PITCH [deg]      CT        CP         CPV       CB         CBV
       1    7.5850    3.0000           0.5472   -0.3287     0.0887   -0.3869    -0.0016
       2    5.4180    3.0000           0.5031   -0.3491     0.0314   -0.3475    -0.0011
       …        …          …                  …          …          …          …          …
```

Output Files

- General Output
  - XTurb_Output1.dat

```
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

NREL-PhaseVI                            ***** XTurb-PSU  -  OUTPUT 1 *****
  Blade Number      BN =  2

  Solidity
  0.0519
                                   + Prescribed Wake Method [Chattot, Schmitz] +

  Number   TSR      PITCH [deg]      CT        CP        CPV       CB        CBV
       1   7.5850   3.0000           0.5472  -0.3287   0.0887  -0.3869  -0.0016

  "Thrust"   >   0      =>      Downwind Direction
  "Torque"   <   0      =>      Energy Extraction (Wind Turbine)   =>   Power = Torque * TSR
  "Bending"  <   0      =>      Flap Bending towards Downwind

  r/R  Chord/R Twist[deg] AOA[deg] PHI[deg] CL     CD     CL/CD    VSEC    VSECX  VSECY  VSECZ
------------------------------------------------------------------------------------------------
0.2500  0.1465  24.8560  -0.8872  23.9688  0.0417 0.0130 3.1985  2.1389  0.8689 -0.0140  1.9545
0.2512  0.1464  24.7223  -0.7218  24.0005  0.0612 0.0132 4.6444  2.1466  0.8731 -0.0139  1.9610
0.2546  0.1460  24.3221  -0.2279  24.0941  0.1191 0.0134 8.8652  2.1695  0.8857 -0.0138  1.9804
        …                   …                              …                              …
```

Output Files

- General Output
  - XTurb_Output2.dat

```
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

NREL-PhaseVI                            ***** XTurb-PSU  -  OUTPUT 2 *****
  Blade Number      BN =  2

  Solidity
  0.0519
                                 + Prescribed Wake Method [Chattot, Schmitz] +

  Number   TSR      PITCH [deg]      CT        CP        CPV       CB        CBV
       1   7.5850   3.0000           0.5472  -0.3287   0.0887  -0.3869  -0.0016

  "Thrust"   >   0      =>      Downwind Direction
  "Torque"   <   0      =>      Energy Extraction (Wind Turbine)   =>   Power = Torque * TSR
  "Bending"  <   0      =>      Flap Bending towards Downwind

r/R   Chord/R Twist[deg] AOA[deg] CL     CD     CDP     CM     CThrust  CTorque  CNormal  CTangen
-----------------------------------------------------------------------------------------------
0.2500 0.1465 24.8560  -0.8872   0.0417 0.0130 0.0067 -0.0408 0.0434  -0.0013   0.0415  -0.0137
0.2512 0.1464 24.7223  -0.7218   0.0612 0.0132 0.0067 -0.0413 0.0612  -0.0032   0.0610  -0.0139
        …                   …                             …                             …
```

Output Files

- General Output
  - XTurb_Output3.dat

```
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

NREL-PhaseVI                              ***** XTurb-PSU  -  OUTPUT 3 *****
  Blade Number      BN =  2

  Solidity
  0.0519
                                   + Prescribed Wake Method [Chattot, Schmitz] +

  Number   TSR      PITCH [deg]      CT        CP        CPV       CB        CBV
       1   7.5850   3.0000           0.5472  -0.3287   0.0887  -0.3869  -0.0016

  "Thrust"   >   0      =>      Downwind Direction
  "Torque"   <   0      =>      Energy Extraction (Wind Turbine)   =>   Power = Torque * TSR
  "Bending"  <   0      =>      Flap Bending towards Downwind

r/R  Chord/R Twist[deg] AOA[deg] PHI[deg] CL   CD    CL/CD  CThrust  CThrustV CTorque CTorqueV CBending CBendingV
-----------------------------------------------------------------------------------------------------------------
0.2500 0.1465 24.8560  -0.8872  23.9688 0.0417 0.0130 3.1985 0.0434   0.0053  -0.0013   0.0030  -0.0109  -0.0013
0.2512 0.1464 24.7223  -0.7218  24.0005 0.0612 0.0132 4.6444 0.0612   0.0054  -0.0032   0.0030  -0.0154  -0.0013
          …                   …                              …                              …
```

Output Files

- Method Specific Output (HVM)
  - XTurb_Output_Method.dat

```
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

NREL-PhaseVI                           ***** XTurb-PSU  -  OUTPUT 3 *****
  Blade Number      BN =  2

  Solidity
  0.0519
                                 + Prescribed Wake Method [Chattot, Schmitz] +

  Number   TSR      PITCH [deg]      CT        CP        CPV       CB        CBV
       1   7.5850   3.0000           0.5472  -0.3287   0.0887  -0.3869  -0.0016

  "Thrust"   >   0      =>      Downwind Direction
  "Torque"   <   0      =>      Energy Extraction (Wind Turbine)   =>   Power = Torque * TSR
  "Bending"  <   0      =>      Flap Bending towards Downwind

  "Axial   Induction Factor"   a       = -ui
  "Angular Induction Factor"   a_prime = +wi/(r/R*TSR)

r/R  Chord/R Twist[deg] AOA[deg] PHI[deg] CIRC   CL    CD    CL/CD   ui     vi     wi     a    a'
 ---------------------------------------------------------------------------------------------
0.2500 0.1465 24.8560  -0.8872  23.9688  0.0000 0.0417 0.0130 3.1985 -0.1311 -0.0140  0.0582   0.1311   0.0307
0.2512 0.1464 24.7223  -0.7218  24.0005 -0.0096 0.0612 0.0132 4.6444 -0.1269 -0.0139  0.0559   0.1269   0.0294
 …                             …                             …                                  …
```

Output Files

- Method Specific Output (BEMT)
  - XTurb_Output_Method.dat

```
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

NREL-PhaseVI                                  ***** XTurb-PSU  -  OUTPUT - METHOD *****
  Blade Number      BN =  2

  Solidity
  0.0519

                      +    BLADE ELEMENT MOMENTUM THEORY (BEMT)   +

  Number   TSR      PITCH [deg]      CT        CP        CPV       CB        CBV
       1   7.5850   3.0000           0.5420  -0.3229   0.0881  -0.3836  -0.0016

  "Thrust"   >   0      =>      Downwind Direction
  "Torque"   <   0      =>      Energy Extraction (Wind Turbine)   =>   Power = Torque * TSR
  "Bending"  <   0      =>      Flap Bending towards Downwind

  "Axial   Induction Factor"   a       = -ui
  "Angular Induction Factor"   a_prime = +wi/(r/R*TSR)

r/R  Chord/R Twist[deg] AOA[deg] PHI[deg] CL     CD     CL/CD    FR     FT     ui     wi     a       a'
 ------------------------------------------------------------------------------------------------------
0.2500 0.1465  24.8560  -0.9001  23.9559   0.0402 0.0130   3.0846 0.0008 0.9990  -1.0000 -1.8962 1.0000  -1.0000
0.2512 0.1464  24.7223  -0.7680  23.9543   0.0557 0.0131   4.2431 0.0959 0.9996  -0.1418  0.0268 0.1418   0.0141
```

Output File - Convergence

- Convergence Output
  - XTurb_Convergence.dat

Gives some information on convergence problems that were encountered during the solution process.

Is quite helpful to isolate specific cases of TSR and Tip Pitch that may produce non-physical results.

Output Files - *gnuplot*

- Output Files for *gnuplot*
  - XTurb_gnuplot_data.plt
  - XTurb_gnuplot_script.plt
  - XTurb_gnuplot_global_data.plt
  - XTurb_gnuplot_global_script.plt

GNUPLOT = 1 (global data and global script files)

GNUPLOT = 2 (all four files)

- Run *gnuplot* (in terminal)

```
gnuplot   XTurb_gnuplot_script.plt
```

… creates a folder GNUPLOT/ with *.png plots.

```
gnuplot   XTurb_gnuplot_global_script.plt
```

… creates a folder GNUPLOT_GLOBAL/ with *.png plots.

Future Developments XTurb-PSU

- Unsteady HVM – Shed Wake
- Vortex Rollup in HVM
- Optimization in HVM
- Tower Shadow Model
- Stall-Delay Model
- Wind Farm Wake Modeling

=> M.S. & Ph.D. Theses !!!