

## USING 3-D MODELLING AND SIMULATION - OPTIMIZING THE PERFORMANCE OF COMPOSITE WIND TURBINE BLADES

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### ABSTRACT

Optimizing the design and utilization of best procedures in manufacturing the turbine blades, with a suitable composite materials is in the need of hour. As only 75-80% of Betz limit (i.e. only 16/27 or 59.3% could only be captured from the total available kinetic energy in the wind flow) can be achieved under practical utility conditions. So there is a need to increase the output power of the wind turbine system, under the normal atmospheric conditions. Change of blade's aerodynamic shape and use of suitable composite materials, may lead to increase in the efficiency of wind turbine, which in turn increases the operable profits. Optimizing structural composites in blade design is not an easy task, as we must take the account of center of gravity, aerodynamics of blade profile, proper mounting and elastic blade center so that these will not affect the smooth working of blades and also induce vibration. So modelling of different composite blades by NuMAD and simulating them by using Finite Element packages like ANSYS, and thus calculating the static, dynamics and buckling of composite blades. By this we can in turn analyze the wind turbine blades for low turbulence characteristics on blades, high performance and also increasing the working life with low maintenance. Thus for designing the blade, blade profile data are taken from NREL database and thus organized and then fed to NuMAD for successful design of composite blades. Composite blades with high reliability has a wide scope in industry, and also a need of hour.

**KEYWORDS** Composite Blades, NuMAD, Finite Element Analysis, ANSYS, Wind Turbine Generator, NREL.

Abandoning (or) Reducing dependence on fossil fuels and Non-Conventional resources is inevitable to Mankind, be it by their Availability globally, or else due to their impact environmentally. Non-Polluting or Green Energy is winning accolades internationally, and is required for the sustainable development of our planet. For green energy, wind power has become a pioneer in last few decades, due to increase in the tower height and blade span radius.

For Modern Wind Turbines there has been a dramatic change in the design of blades over the years. Now focus is mainly on using composites for blade manufacturing, so as this would reduce the inertia of blades and thus could convert maximum part of Kinetic Energy of Wind into useful work.

As we know that Manufacturing of Blades of Wind turbines is by Lay-up Method, Design and Analysis of blades should also require the same kind of approach even for Composite material.

Composites should be carefully selected as it should possess the required properties for design, manufacturing, as well as transportation. The composition of composites in all the places of blades is not taken uniformly,

i.e. different compositions at Leading edge (le), Trailing edge (te), Cap, Shear Web etc.

Blade profile data is taken from NREL laboratory website. Blade profile which are tested in wind tunnel is selected and then design of composite blades are done in NuMAD software, these files are converted into input files for ANSYS, and analysis is done, which makes us find the reliability of the design produced.

For Analysis, Static as well as Buckling Analysis is done on the design of composite blades produced by NuMAD. For buckling analysis, appropriate load steps and sub steps are taken which in turn make load shapes.

Main factors like Wind speed and Swept area of Blades of WTG, are responsible for conversion of kinetic energy to Rotational kinetic energy, 30% of Maximum Efficiency of blades occur at a tip speed ratio of 11.6 [Sarkar and Behera, 2012]. Skin friction and wind pressure has integrated effect on Aerodynamic force and aero foil surface, this effect should be considered [Schubel and Crossley, 2012].

In NuMAD a 3-D blade model which is reliable can be created using user defined Composite materials. Design requirement for small wind turbines are taken care as per

IEC norms. Improving the blade design and also reducing the inertia, helps to capture more energy from the kinetic energy of wind and this region has a wide potential and scope.

## LITERATURE REVIEW

An initial layout for 2 MW composite blade of wind turbine is discussed and new airfoil families are selected for the same 2 MW type, a parametric model of blade in finite element is generated. By modified Momentum theory on blade element, a new interaction method of fluid–structure for one-way is introduced. In this, a procedure that combines Particle Swarm Algorithm (PSA) and Finite Element Analysis (FEA) for optimizing composite structure of blades of WTG is developed. This paper proposed not about only thickness variation but even regarding permits to location variation in spar cap structure. The results shown, are compared with initial blade, the mass of the blade that is optimized is reduced and thus exhibit more saving of mass. This study has much significance in optimization and structural design for blades of wind turbine [Chen et. al., 2013].

In this research, length of blade is taken as 1.5m and profile is considered as NACA 2412 which is modelled from composite fiber of reinforced polymer, which has 7, 9, 11, 13, 15 layers of mat with epoxy resin and fiber glass fabric as a matrix. Static analysis is conducted and risk areas are determined by taking maximum values of normal and tangential stresses. Structural optimization and verification is then performed and the stress and strain state is compared with the results initially. It was also found that, increasing the number of layers in risk areas and blade tip reduction, increases the blade resistance for static and dynamic loads [Domnica et. al., 2016].

In this study a design (structural) which is meant for composite wind turbine blades of medium scale i.e. 750 KW class is done. Design loads are determined from IEC 61400-1. A specific configuration of composite structure is proposed which effectively endures loads like Aerodynamic, Mechanical, Hygro-thermal and loads occurring due to ice accumulation. Moreover Blade is adopted with new type of blade root joint which have inserted bolts which increases its safety and this is even verified for fatigue loading. A static structural test on full scale is also performed and prototype blade is certified by International Certification Institute

successfully, which is placed at GL in Germany [Kong et. al., 2005].

In this paper they optimizing the use of material in composite blade of fiber glass of 2.5m long. A program to create a finite element mesh of blade by design data from element blade theory in a format, that is suitable for using it as a direct input into commercial FEM packages. A simulation of rotating aerodynamically loaded blade is done using non-linear analysis. Many arrangements are made in the element theory of blade to minimize both tip deflections and also maximum stress value at operating design conditions [Bechly and Clausen, 1997].

Aero elastic analysis of composite wind turbine blades in its full scale is done by a 3-D Model. 3-D finite element model is built to investigate aero elastic behavior and also influence of deformation on the power performance is also determined. Dynamic instability is also investigated and so this dynamic instability is found out at high wind speeds [Rafiee et. al., 2016].

In this study for a full-scale composite wind turbine, a collapse test under flap-wise loading is done. Videometrics technique is used for measuring local, integral deformation of blade in wind turbine under flap-wise bending. In results that are measured, the displacement at the tip is up to 11m and ultimate load ( $U_L$ ) is 160% of designed load. Also a method is formulated for identification of exact failure location based and as per deformation data. In thorough analysis, findings were the initial failure mechanism is due to shells debonding from adhesive joints, and this causes blade structure for progressive collapse [Yang et. al., 2013].

For this paper, the failure behavior in skin stiffer structure of composite blade wind turbine are thoroughly investigated. For achieving this, composite beams are laminated with carbon, glass and Yarns of Kevlar before the commencement of process of Curing. Four different moulds i.e. T-beam, Box beam with Adhesives, T-beam, Box beam with stitches are studied. Quasi-static loading is used to test the specimens for failure resistance in stitched and adhesive methods of bonding. Results of this Quasi-static loading indicated an improvement in both inter-laminar fracture and failure load due to stitching process. A technique called Cohesive Zone Modelling (CZM) is also done which is used to predict bonding failures in structures [Al-Khudairi and Ghasemnejad, 2015].

Turbulence characteristics of different wind turbines are studied in this paper. Large scale, small scale wind turbines are well investigated for design and turbulence characteristics. Complex environments and fatigue is considered in every case. Different heights i.e. 33m to 97m is taken and their turbulence data is analyzed with Normal Turbulence Model (NTM) as per IEC [Carpman N., 2011].

**DESIGNING OF WTG BLADES BY NuMAD**

Sandia National Laboratories, had prepared a design software for designing Blades of WTG, keeping in mind of lay-up process in manufacturing and Composite materials that are used. The Tool is called NuMAD (Numerical Manufacturing And Design tool), which takes out the basic problems in designing of blades of WTG.

NuMAD, reduces the energy for design and increase the reliability of WTG’S, by improving blade design and manufacturing. This NuMAD model can be used for 3-Dimension Analysis and thus a Reliable Composite blade model can be generated. Model Re-usability and quite less time consumption are the salient features of this tool.

NuMAD has a standard Pre-Processor for ANSYS Mechanical APDL commercial Finite Element Package. NuMAD can create ANSYS input files in stand-alone mode

and thus could create a seamless interface, thus producing files for Analysis of designs produced.

NuMAD interface has 3 main areas,

1. Menu Bar, 2. View Port, and 3. Control Panels

**Menu Bar**

The main menu bar, groups various program functions together into a few drop-down menus. The File menu creates, opens, and saves blade project files. The Blade, View, and Materials menus perform functions associated with blade model creation. The ANSYS and Plot3D menus perform output-related functions.

**View Port**

The viewport displays the blade geometry and provides an interactive graphical interface.

**Control Panel**

The control panels provide access to the currently selected station’s data. The buttons are grouped into three panels: Station Parameters, Skin Material Division Points, and Shear Webs. Some of the panels and controls may be inactive depending on the program state.

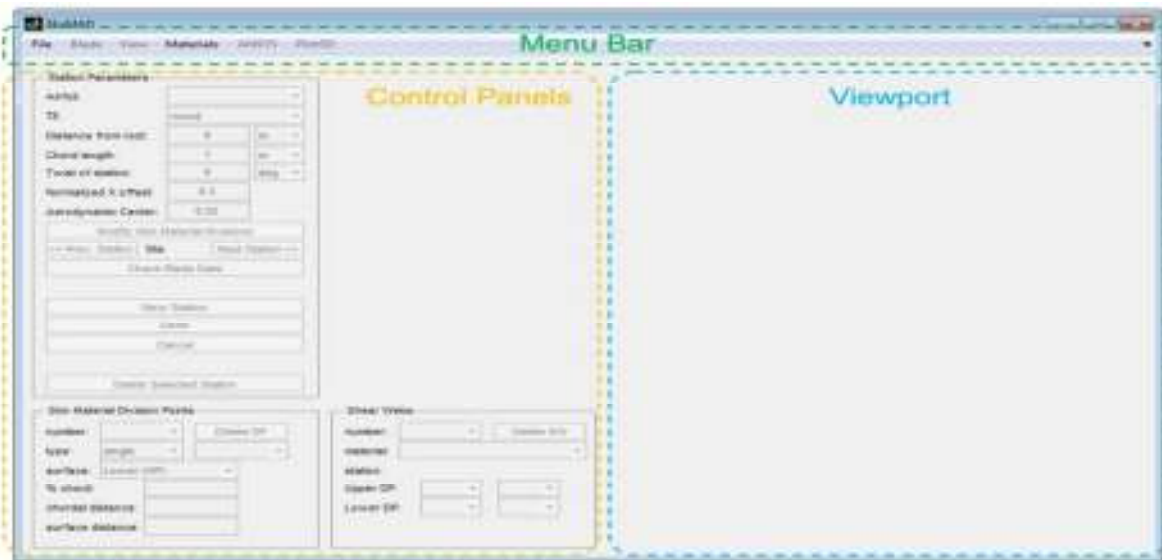


Figure 1: NuMAD interface

**Modelling of Composites**

Blade modelling in NuMAD is done by adding stations at specific intervals based on the blade length and design that is preliminarily considered.

**Design of Composite Material**

But before that Composite materials are created by blending existing database of different Isotropic and Orthotropic materials. i.e. thickness of layers of materials to

be used for Root, leading edge, trailing edge, cap, shear web etc. Their thickness and compositions are selected as below :

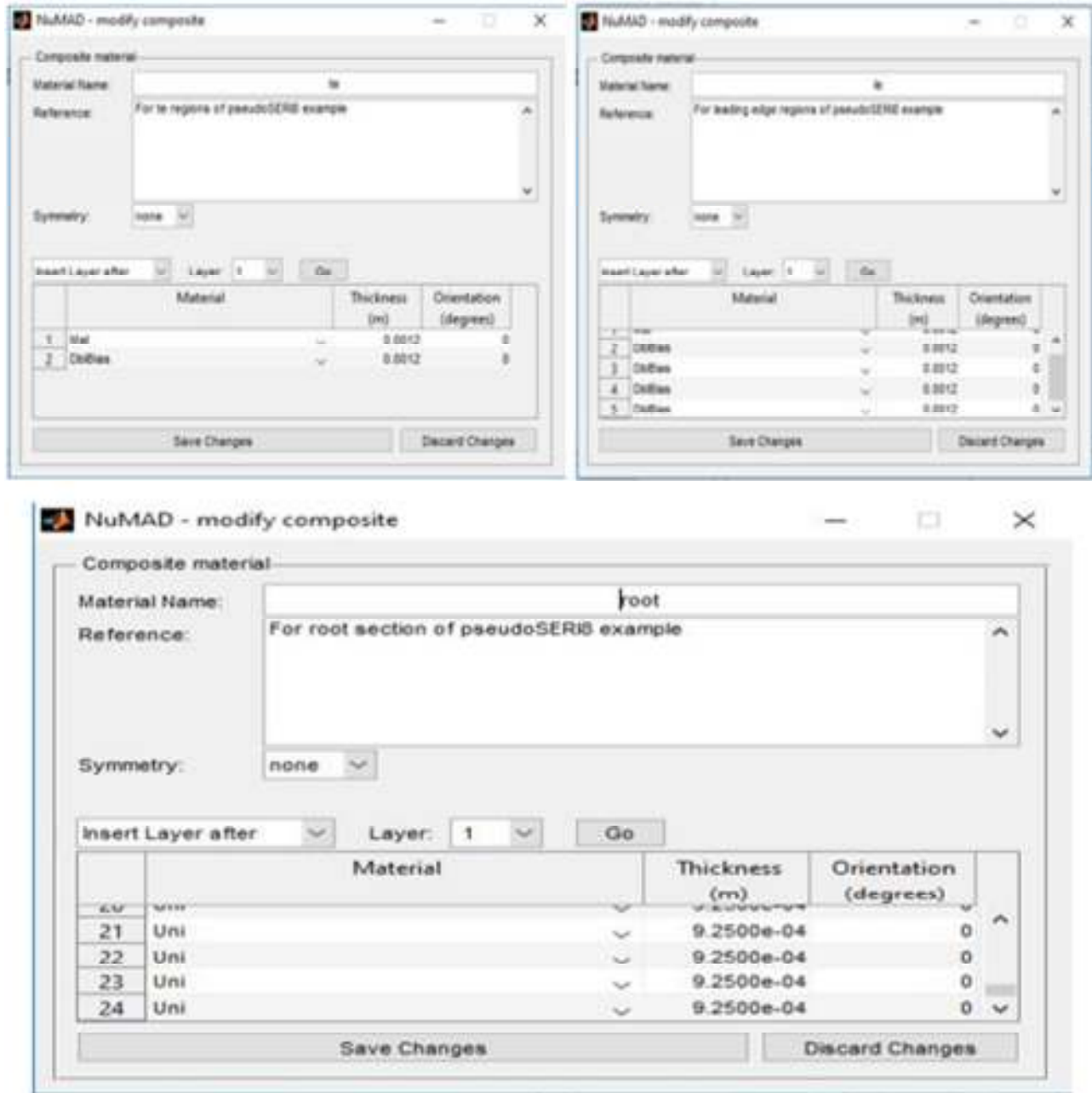


Figure 2: Composites Preparation

Now after defining the composite laminates, designing of Blade profile is started. Different stations in between the length of the blade is added accordingly w.r.t the dimensions of the design.

**Model-1 Design**

Wind turbine blade which is of composite materials is designed with a length of 10m, as we had already designed composite materials and Airfoil shapes for NuMAD, we load and save them in the database of

NuMAD. In Model-1, a composite blade without shear web is designed.

Station Parameters with respect to design are given accordingly, i.e. their Airfoil shape, Chord length, Twist, Offset etc.

**Table 1: Station Parameters for Model-1**

Station	Airfoil	Location (m)	Chord (m)	Twist (deg)	X-offset
<b>1 (root)</b>	circular	0.00	0.2	30	0.3
<b>2</b>	circular	0.50	0.25	28	0.3
<b>3</b>	S825	1.50	0.7	25	0.3
<b>4</b>	S825	3.0	1	30	0.3
<b>5</b>	S826	5.0	0.7	25	0.3
<b>6</b>	S826	7.0	0.5	20	0.3
<b>7</b>	S826	9.0	0.3	15	0.3
<b>8 (tip)</b>	circular	10.0	0.1	10	0.3

Now after these station parameters are exactly given in the Control Panel of the interface, the design obtained in the View Port of the NuMAD interface is like follows :



**Figure 3: Different Stations for WTG Blade Design-1**

Now adding Division Points on the different stations created above so that, applying of different compositions of Composites can be a reality. Materials

created before can thus be added by Right-click on the mouse at the designated station and applying the material.

Division point's w.r.t, % chord is given below :

**Table 2: Division Point's location for Model-1**

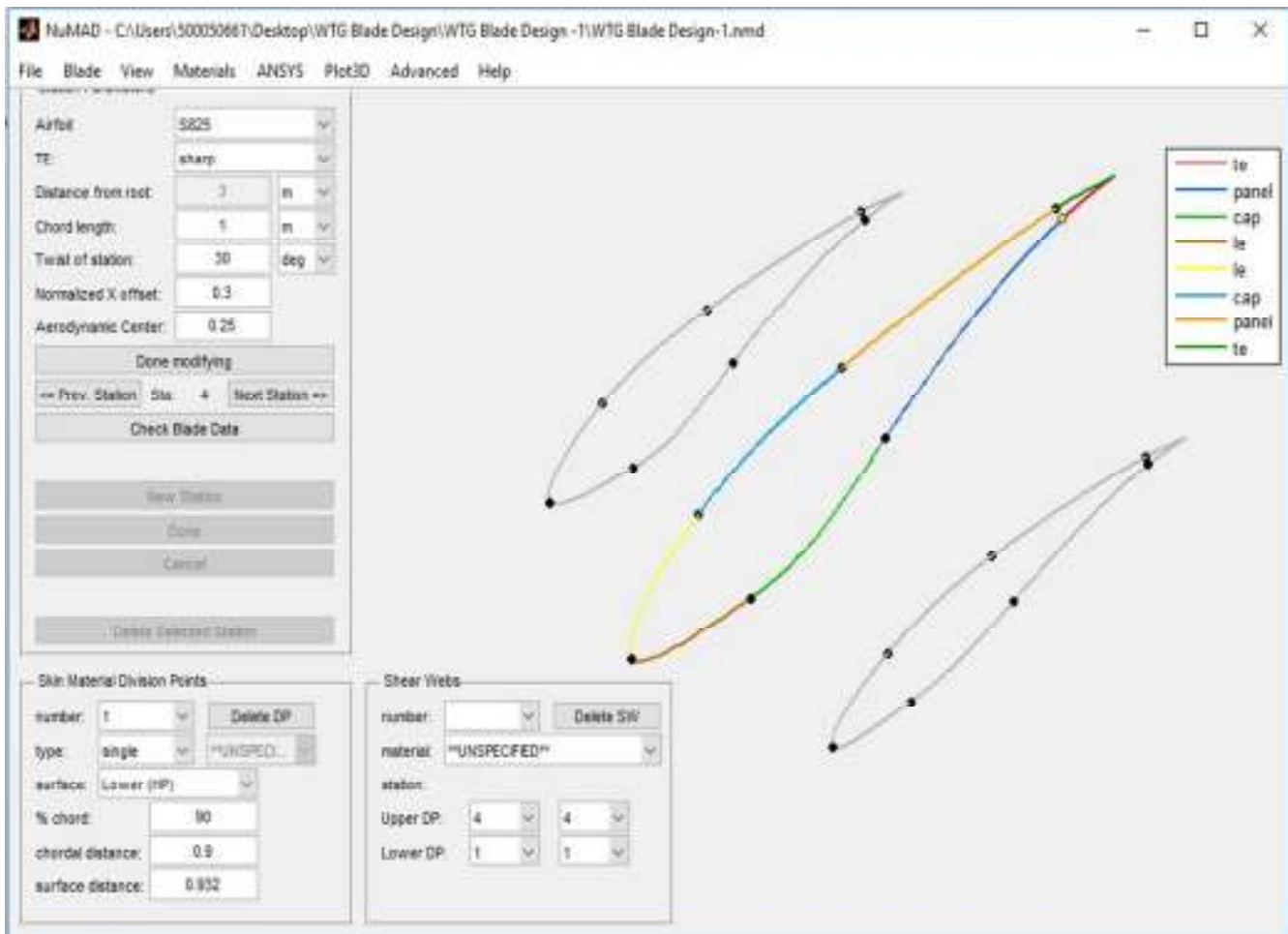
Stations	Lower surface Division Point's - % chord				Upper surface Division Point's - % chord		
	<b>1-2</b>	90	60	10	0	10	60
<b>3-8</b>	90	50	20	0	20	50	90

**Table 3: Material Assignment's for Model-1**

<b>Segments:</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>
<b>Stations: 1</b>	Root	Root	Root	Root	Root	Root	Root	Root
<b>Stations:2-7</b>	Trailing Edge(te)	Panel	Cap	Leading Edge(le)	Leading Edge(le)	Cap	Panel	Trailing Edge(te)

After Divisional Point's and Material Assignment the model should look like as follows. Different Composite materials which are created for Leading Edge, cap, trailing

edge are assigned respectively and it looks like following image.



**Figure 4: Division Points (DP's) division for each station**

After verifying all the data, a Blade Data check is performed on the Designed Model and as all the stations are

assigned with materials and appropriate Division Points are correlated, Design is generated as follows.

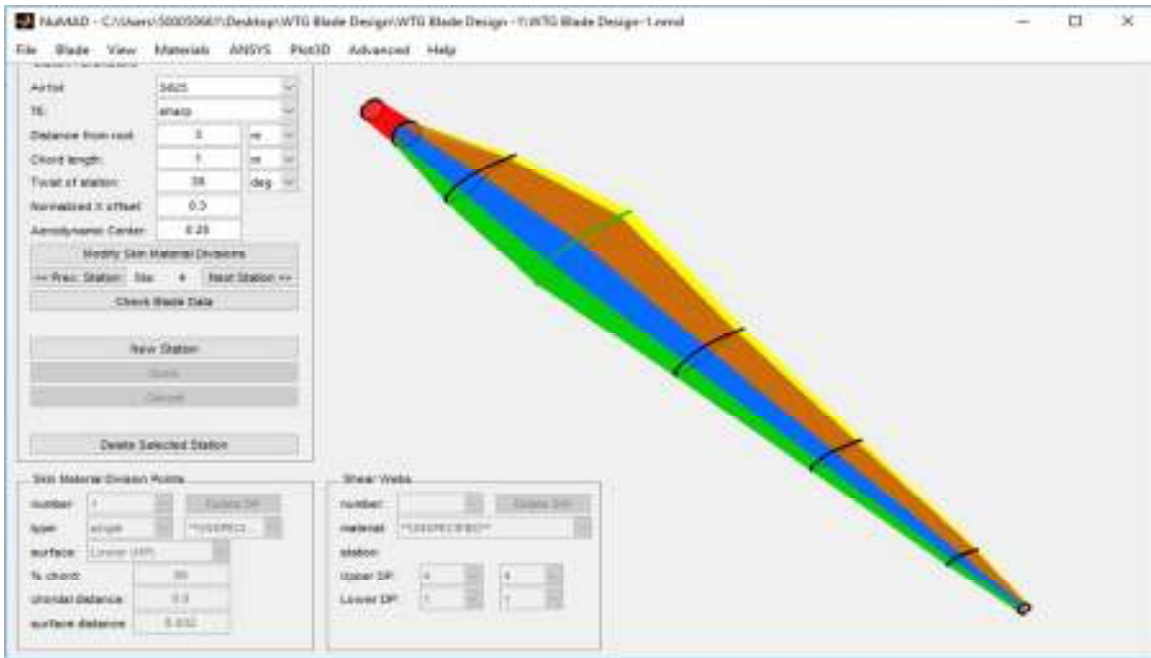


Figure 5: WTG Blade Design-1 with skin materials in NuMAD

**Model-2 Design**

Now Designing another Model blade which has a Shear Web, for this blade a length of 7.925m from hub to tip is taken. So as shear web is incorporated in this model, this might be an advancement of previously created model.

For adding new station's for NuMAD interface, there is a need to follow as per the below mentioned procedure, in which all the parameters i.e. location, airfoil shape etc are to be given for successful creation of stations.

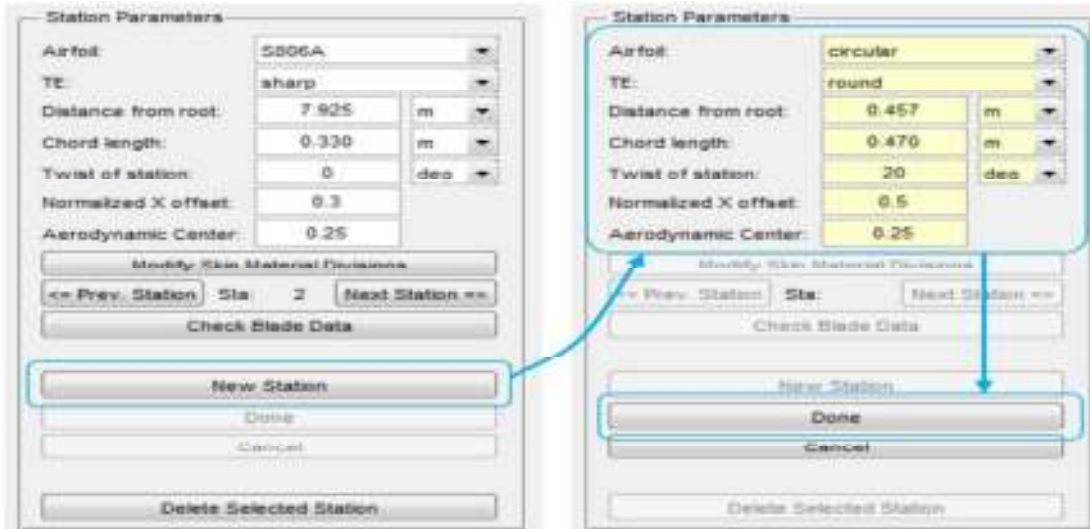


Figure 6: Model for Preparing Station Parameters

The following table consists of the station parameters that needed to be created for this model, which contains shear web.

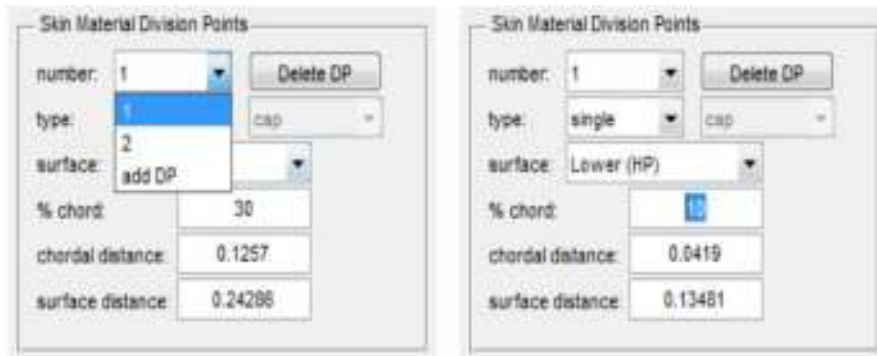


**Table 4: Station Parameters for Model-2**

Station	Airfoil	Location (m)	Chord (m)	Twist (deg)	X-offset
<b>1 (root)</b>	circular	0.000	0.419	20	0.5
<b>2</b>	circular	0.457	0.470	20	0.5
<b>3</b>	S808	1.524	1.118	20	0.3
<b>4</b>	S807	2.250	1.092	15.7	0.3
<b>5</b>	S805AS807	4.074	0.914	4.22	0.3
<b>6</b>	S805A	5.898	0.665	0.59	0.3
<b>7</b>	S806A	7.518	0.404	0.01	0.3
<b>8 (tip)</b>	S806A	7.925	0.330	0	0.3

For all the stations created above, there is a need to create DP's, so that Skin Materials can be added to the assigned DP's. These skin materials that are prepared by

composite materials are loaded after creation of DP's. The following depicts the procedure for adding of additional DP's.



**Figure 7: Division points addition**

Adding of different stations are carried as below procedure, and thus required station parameters are added as per the table below. Divisional Points are created and

composite materials that are created are added for the segments as designed accordingly.

**Table 5: Division Point's location for Model-2**

Stations	Lower surface Division Point's - % chord				Upper surface Division Point's - % chord		
	<b>1-2</b>	90	60	10	0	10	60
<b>3-8</b>	90	50	20	0	20	50	90

**Table 6: Material Assignment's for Model-2**

Segments:	1	2	3	4	5	6	7	8
<b>Stations: 1</b>	Root	Root	Root	Root	Root	Root	Root	Root
<b>Stations:2-7</b>	Trailing Edge(te)	Panel	Cap	Leading Edge(le)	Leading Edge(le)	Cap	Panel	Trailing Edge(te)

After assigning of material, Shear web is designed for which different stations from 3 to 6 are considered and thus divisional points are added on the

respective stations as per the details in the table given below. Addition of shear web is as follows.





Figure 8: Addition of Shear web

So as per the design, additional DP's are accommodated and thus created, the table below depicts the exact location to create those DP's

Table 7: Divisional points for Shear web in Model-2

Station	% chord of new Division Point's	
	Lower surface	Upper surface
3	28	35
4	29	34
5	31	32.5
6	32	32

Thus after the shear web creation the model in the view port of the NuMAD interface is as follows :

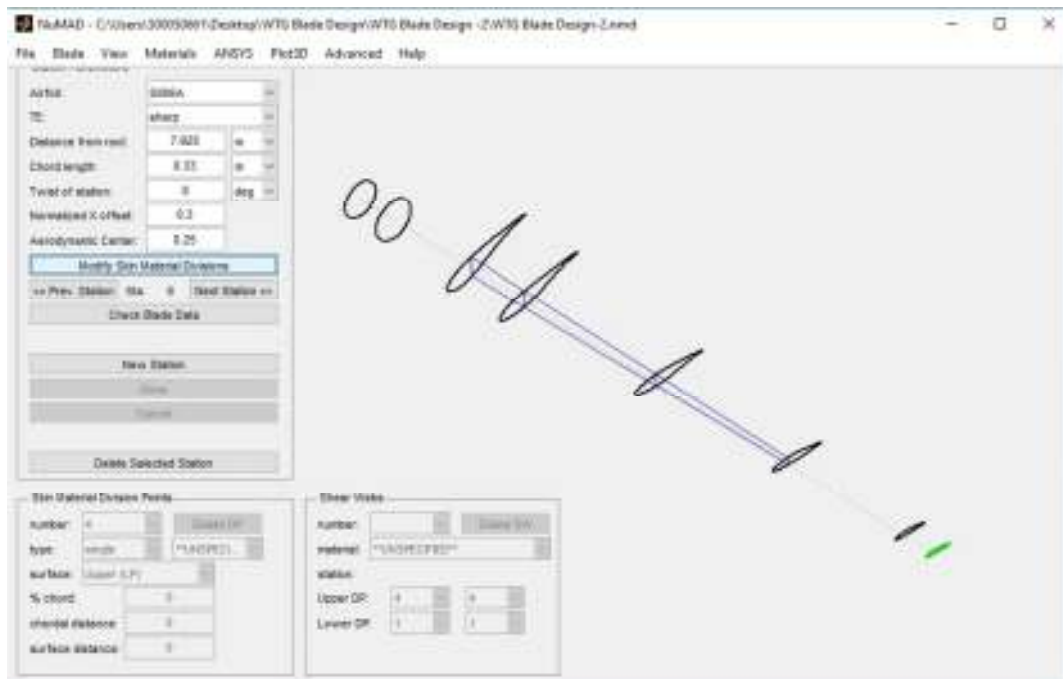


Figure 9: Different Stations for WTG Blade Design-2

After verifying all the data, a Blade Data check is performed on the Designed Model and as all the stations are assigned with materials and appropriate Division Points are

correlated, as shear web is also formulated. Composite Blade Design is generated as follows.

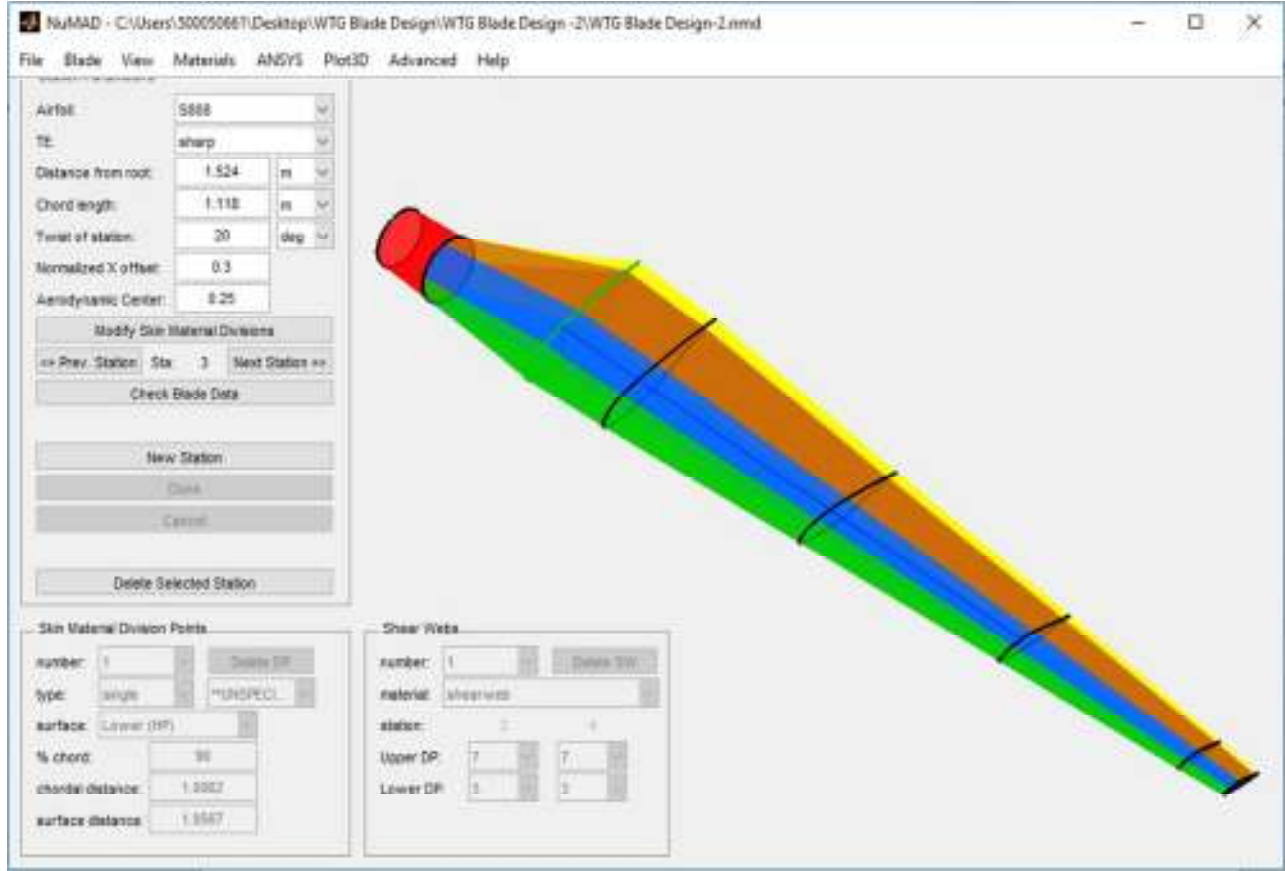


Figure 10: WTG Blade Design-2 with skin materials in NuMAD

So, now design of blades are completed as per NuMAD, now it is to be analyzed for static as well as buckling loads.

**ANALYSIS OF DESIGNED BLADES**

As designing of blades is done in NuMAD, there is a need to convert the files into input files for ANSYS Mechanical APDL. So before beginning of Analysis we need to generate input files which can be fed into ANSYS package.

NuMAD has a Pre-processor to convert the design files into ANSYS input files, it creates APDL commands to create blade model. To create a model we need to specify input conditions in NuMAD interface like

- Specifying boundary conditions
- Choosing an element type and Meshing options
- Selecting output format

Output format “ANSYS Database (.db)” is chosen.

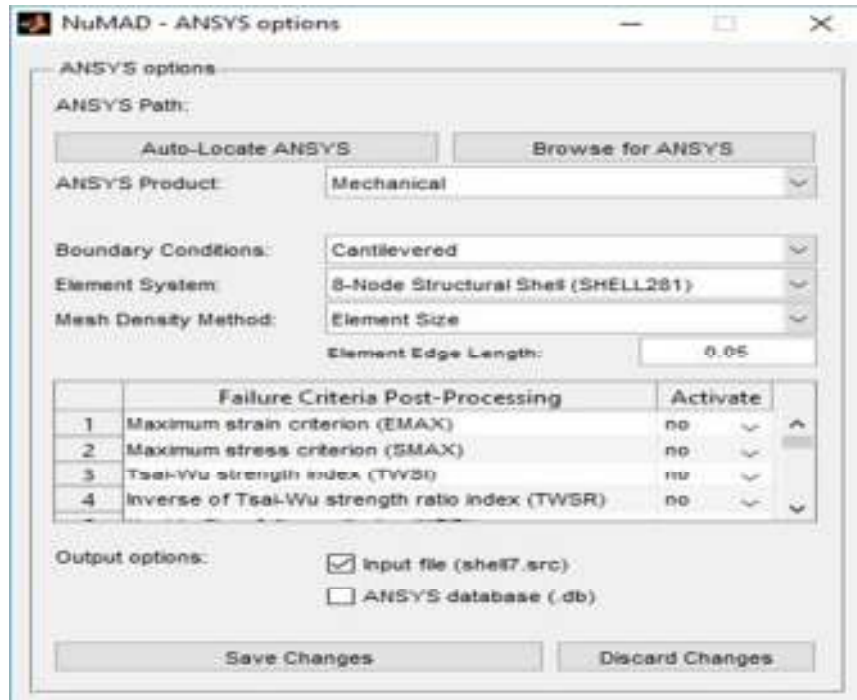


Figure 11: Generating ANSYS input files

Now after saving the changes, clicking on “Generate Now” creates files for ANSYS Mechanical APDL.

Now after launching ANSYS Mechanical APDL, we need to load or read input from the working directory and then generate blade geometry.

**STATIC ANALYSIS**

For static analysis which is used to find isolated locations on the blade, which experiences high strain values. This is used to understand and predict ply failure by defined failure material criteria. In static analysis, load is applied at the tip of the blade which also depicts in flap-wise direction of the blade

**Model-1**

Before starting static analysis we need to load the files of loaded WTG Blade Design-1 and then meshing of files are to be done. After meshing, the design created is as follows.

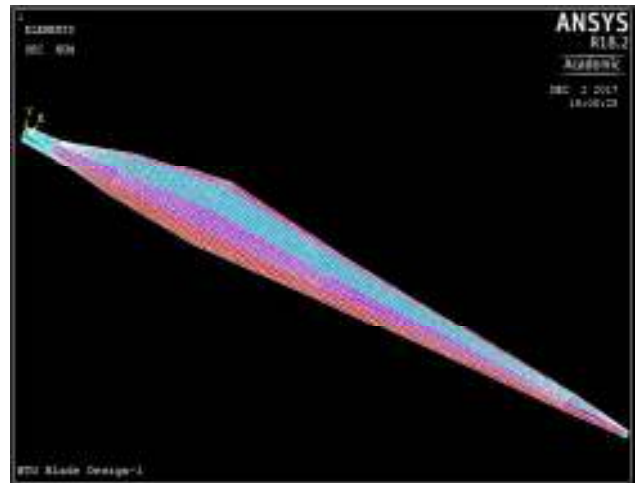


Figure 12: Meshing of WTG Blade Design-1

Now after static analysis, the final result, i.e. Material X-Component of elastic strain in the elements is computed in the post-process of the ANSYS database. Now for WTG Blade design-1, this is as follows.

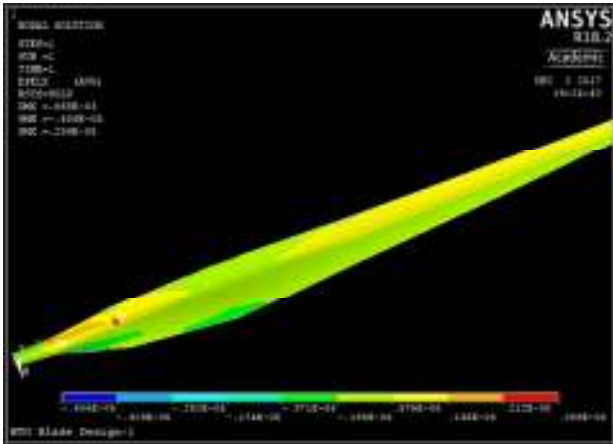


Figure 13: Material X-Component of elastic strain in WTG Blade Design-1

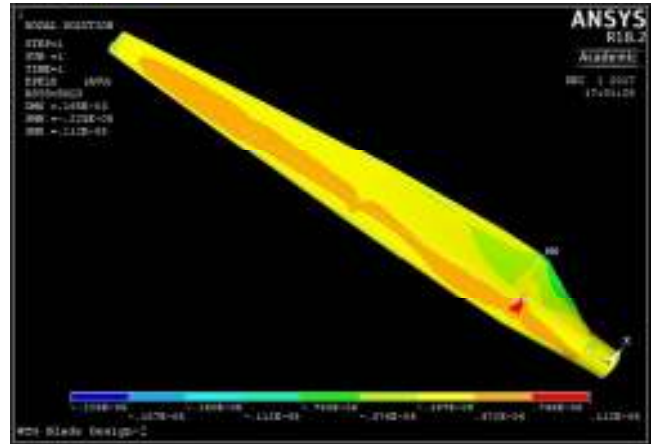


Figure 15: Material X-Component of elastic strain in WTG Blade Design-2

**Model-2**

WTG Blade Design-2 files are loaded into ANSYS Mechanical APDL and meshing of files are completed. Meshing is devised for this blade design as follows

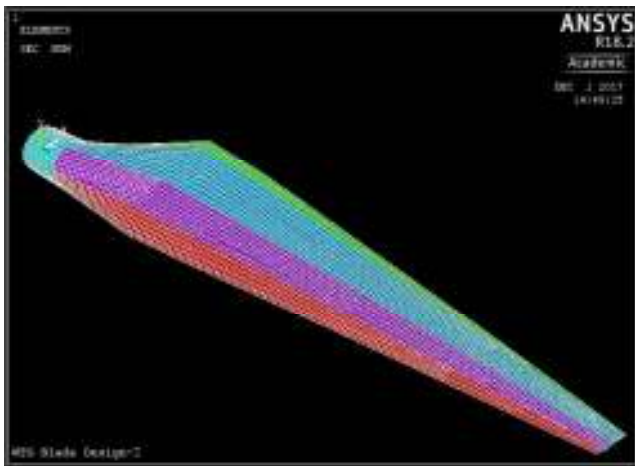


Figure 14: Meshing of WTG Blade Design-2

Now after static analysis, the final result, i.e. Material X-Component of elastic strain in the elements is computed in the post-process of the ANSYS database. Now for WTG Blade design-2, this is as follows

**BUCKLING ANALYSIS**

Both nonlinear buckling and eigenvalue (linear) buckling loads can be computed in ANSYS using the NuMAD-generated model. Eigen value buckling predicts a buckling load which is non-conservative, whereas Non-linear buckling provides more descriptive and accurate results, but analysis is time consuming and quite complex.

Now, for this buckling analysis we are using eigenvalue buckling loads as non-linear one is complex. So now for linear buckling, a point load at the tip of the blade in the flap-wise (downward) direction is taken.

**Model-1**

So for Buckling Analysis, static analysis should be done first and then buckling problem is solved. Here Block Lanczos was taken and 2 buckling modes are extracted.



Figure 16: Fixing the ends of blade for extraction of Modes during Buckling Analysis

SET,LIST Command

File

```

***** INDEX OF DATA SETS ON RESULTS FILE *****
SET      TIME/FREQ      LOAD STEP      SUBSTEP      CUMULATIVE
 1      -1999.4          1              1             1
 2      1646.3           1              2             2
    
```

Figure 17: Results file showing SUBSTEPS

Now expanding mode shapes, Eigenvalue buckling mode shape in aft panel due to flap-wise loading is as follows

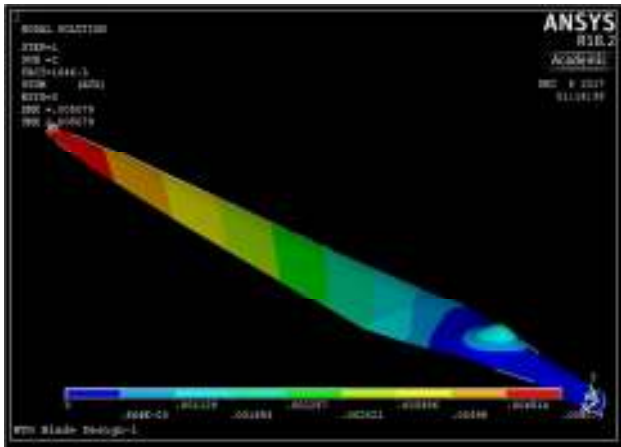


Figure 18: Eigenvalue buckling mode shape in Substep 2 due to flap-wise loading

**Model-2**

So for Buckling Analysis, static analysis should be done first and then buckling problem is solved. Here Block Lanczos was taken and 10 buckling modes are extracted.

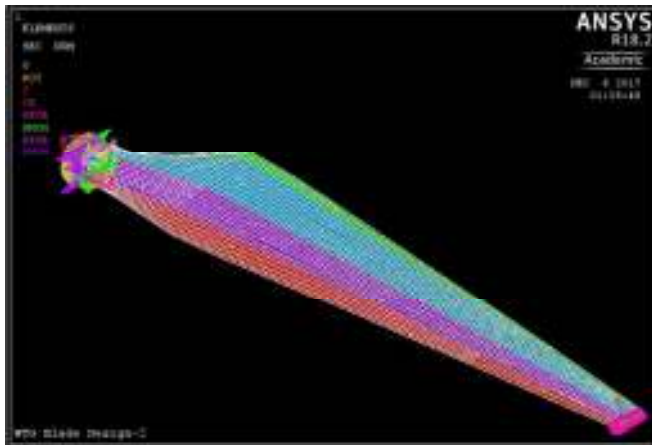


Figure 19: Fixing the ends of blade for extraction of Modes during Buckling Analysis

SET,LIST Command

File

```

***** INDEX OF DATA SETS ON RESULTS FILE *****
SET      TIME/FREQ      LOAD STEP      SUBSTEP      CUMULATIVE
 1      -3530.8          1              1             1
 2      -3331.8          1              2             2
 3      -2969.9          1              3             3
 4      -2850.0          1              4             4
 5      -2566.1          1              5             5
 6      -2505.1          1              6             6
 7      -2328.4          1              7             7
 8      -2317.7          1              8             8
 9      3889.6           1              9             9
10     3912.1            1             10            10
    
```

Figure 20: Results file showing SUBSTEPS

Now expanding mode shapes, Eigenvalue buckling mode shape in aft panel due to flap-wise loading is as follows

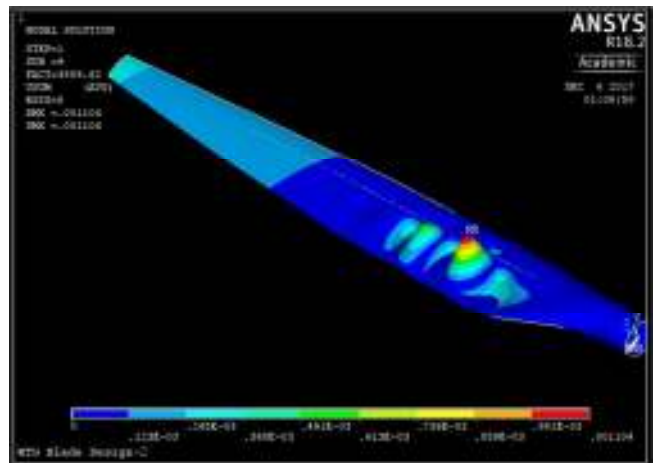


Figure 21: Eigenvalue buckling mode shape in Substep 9 due to flap-wise loading

**CONCLUSION**

Design optimization in NuMAD is done and as airfoil shapes can be easily integrated into NuMAD, various composite blade designs can be produced, but there is a need to check the reliability of different design produced.

Composite wind turbine blade design and Analysis is done on two designs, one without shear web and another with shear web. In Static analysis the place of high stress is to be added with laminates and thus reducing the stress concentration in both the designs.

During buckling loads, the mode shapes are calculated as per the blade designs and the point load that induces buckling is 1.64 kN and 3.88 kN in positive Y-direction.

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