Abhinavmitra Vajjala 8/9/2023

Final Report Out

About Me
Abhinavmitra Vajjala

Personal Information

Hometown: Pittsburgh, PA

School: The Pennsylvania State University

Major: M.S. in Mechanical Engineering (Graduation in Spring 2024)

B.S. in Mechanical Engineering (Spring 2022)

Activities: Graduate Research Student, ASME

Hobbies: Biking, Reading, Hiking, Watching Football, Playing Video Games, Catan

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SOUTHWEST RESEARCH INSTITUTE

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Key Technical Projects

**<u>Worked with Emerging Technologies Team on these tasks</u>**

- Study Blade Geometries by varying parameters in "Blast" and identifying Blades that can meet aeromechanical requirements

- Modified Existing Blast Code to create PS/SS Components as a Solid Model to compare with pure Shell Model, necessary to view sections of airfoil for FRA analysis

- Created BLAST subroutines to have nodes on Pressure and Suction Sides on Blast Models to create elements from those nodes

- Documented an Extensive Overview of Blast Code and Campbell Diagram for future engineers to look at

(a)

(b)

Constraint equations tie airfoil, shank and disk models
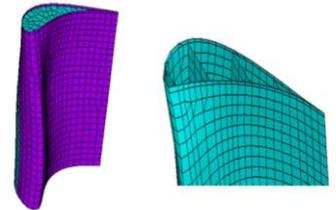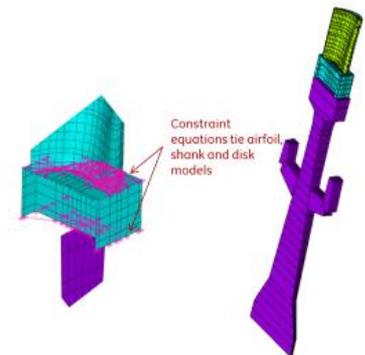
Design of Blades

- Design of Gas Turbine Blades involve numerous engineering fields such as thermodynamics, aeromechanics, and solid mechanics

- Due to the complex nature, Robust designs are needed with multiple design iterations

- With Blast, it outputs an aeromechanical score for each DOE Blade based on the frequency margin which is used for ranking the designs

Background Information on BLAST

- MATLAB tool developed to calculate the natural frequencies of modes of blade designs

- Generates a shell-element based ANSYS Model of the airfoil, shank, disk, and shroud

- Published Paper from ASME Turbo Expo by Suryarghya Chakrabarti

- Input a NACA Geometry File and builds airfoil model with a cyclic symmetry modal analysis at the design speed (rpm)

- Performs a modal analysis on shrouded blades which includes stress effects and temperature loading as constraints

- Quickly generate DOE designs of the blades in minutes with their frequencies recorded

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┌─────────────────┐      ┌─────────────────────────┐      ┌─────────────────────────┐
│                 │      │  Calls DOE Excel Inputs │      │  Calls NACA_4_Digits    │
│     BLAST       │─────▶│  and Runs Blast_Gen_    │─────▶│  Using Hub and Tip      │
│                 │      │  Shell Reads (fid,      │      │  Inputs of Excel        │
│                 │      │  inputs, DOE)           │      │                         │
└─────────────────┘      └─────────────────────────┘      └─────────────────────────┘
                                      │                                │
                                      ▼                                ▼
                         ┌─────────────────────────┐      ┌─────────────────────────┐
                         │  Creates a MACRO File   │      │  Calls inputs of        │
                         │  for ANSYS: Defines     │      │  inlet/exit metal       │
                         │  Element Types and      │      │  angle, axial chord,    │
                         │  Material Properties    │      │  sec_area, stagger      │
                         │                         │      │  angle, to generate     │
                         │                         │      │  airfoil                │
                         └─────────────────────────┘      └─────────────────────────┘
                                      │                                │
                                      ▼                                ▼
┌─────────────────────┐  ┌─────────────────────────┐      ┌─────────────────────────┐
│ PS and SS nodes are │  │  Uses These Coordinates │      │  Outputs the camber     │
│ created and         │◀─│  to Define Nodes and    │◀─────│  line coordinates,      │
│ connected to SHELL  │  │  Elements of AIRFOIL    │      │  section thickness at   │
│ Nodes               │  │  to create SHELL        │      │  each camber line,      │
│                     │  │                         │      │  suction and pressure   │
└─────────────────────┘  └─────────────────────────┘      │  side coordinates.      │
           │                          │             ▲      └─────────────────────────┘
           ▼                          ▼              \                  │
┌─────────────────────┐  ┌─────────────────────────┐  \   ┌─────────────────────────┐
│ Solid Model of      │  │  Outputs Airfoil        │   \  │  Blast_Calc_Normal :    │
│ Airfoil is created  │─▶│  Elements into ANSYS    │    \ │  Uses the Pressure and  │
│ using PS and SS     │  │                         │      │  Suction Coordinates    │
│ nodes               │  │                         │      │  to Calculate Camber    │
│                     │  │                         │      │  Line                   │
└─────────────────────┘  └─────────────────────────┘      └─────────────────────────┘
                                      │
                                      ▼
                         ┌─────────────────────────┐
                         │  Modal Analysis is      │
                         │  Applied to get         │      Contributions to this code are
                         │  Frequencies for        │      represented by Red Boxes
                         │  Campbell Diagram for   │
                         │  FRA                    │
                         └─────────────────────────┘
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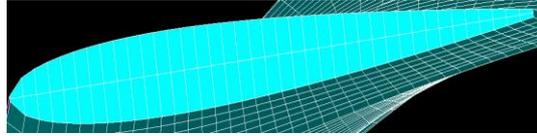
New Model

- Hollow airfoil is built by reading a section file, that loops at 40 iterations, and generates the section between the hub and the tip of the airfoil.

- Original Code calculated Camber Nodes by averaging PS/SS nodes and creates airfoil elements with those nodes

- My code will collect PS/SS Nodes and create airfoil elements with those nodes

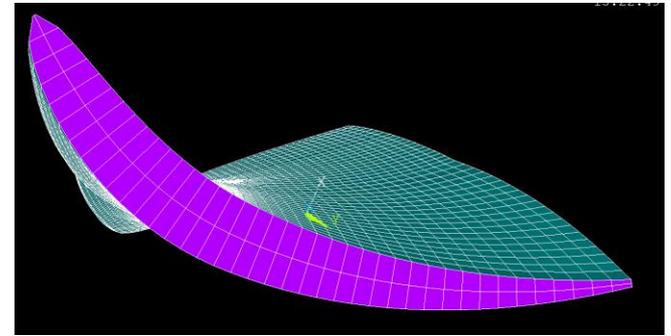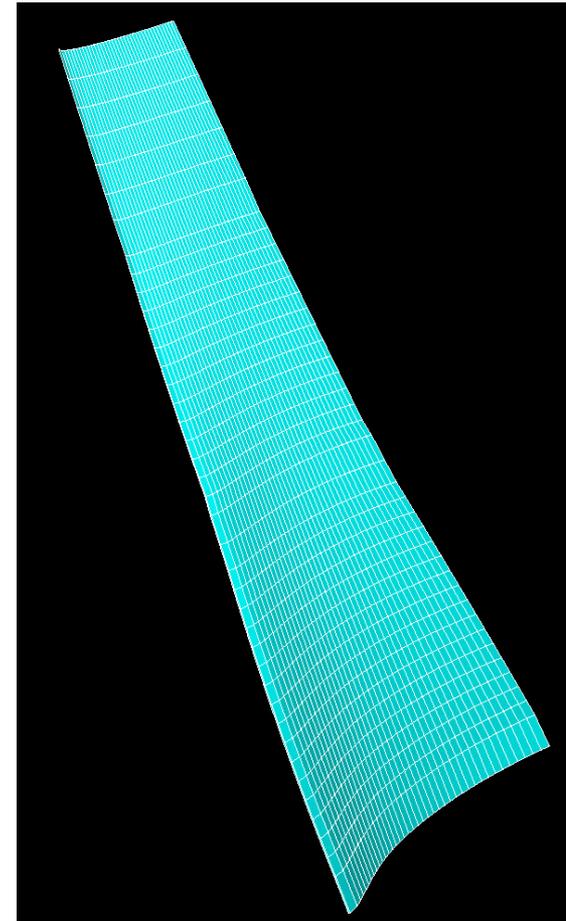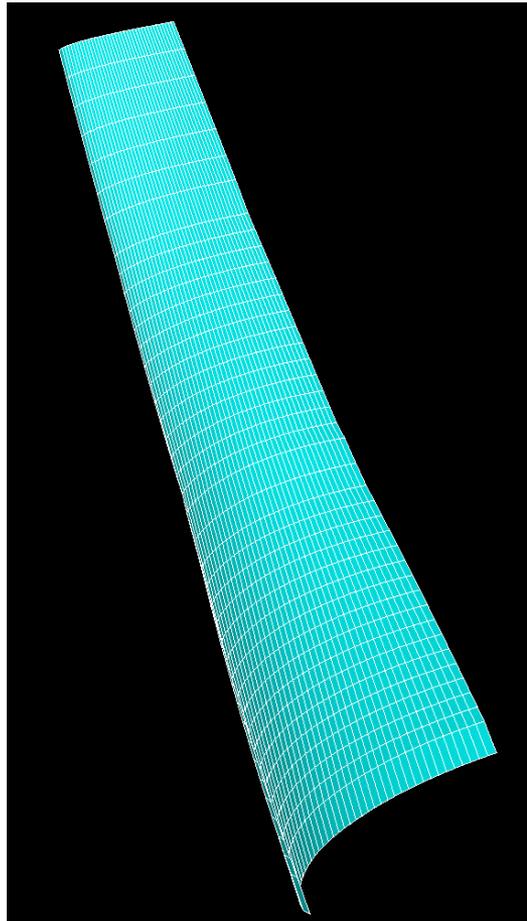- Shell element nodes are then defined on internal surface with shell thickness defined outward at SHELL181

Section geometry → Shell nodes, normals and thickness computed for each section → SHELL model

Shell thickness
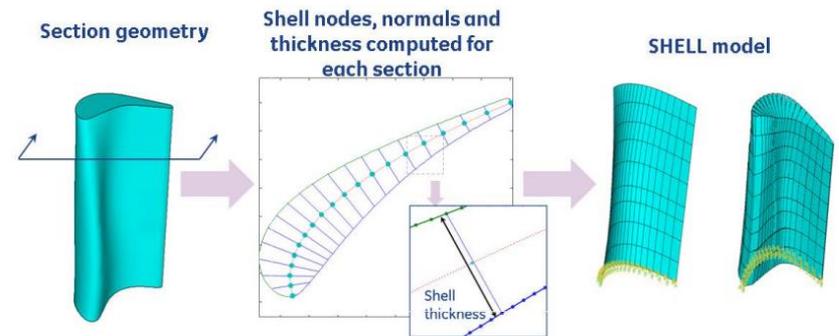
Camber vs PS/SS
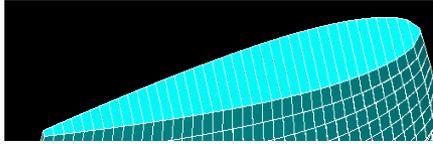
Camber Model

Pressure Side Surface

Suction Side Surface
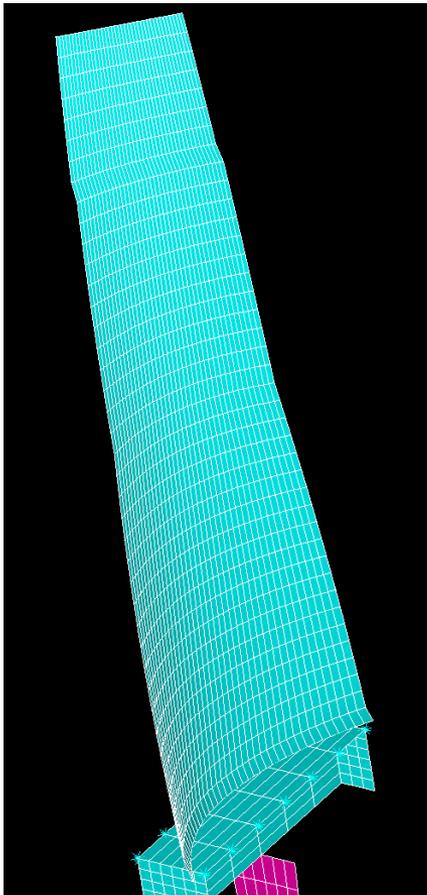
Shell Airfoil with PS and SS
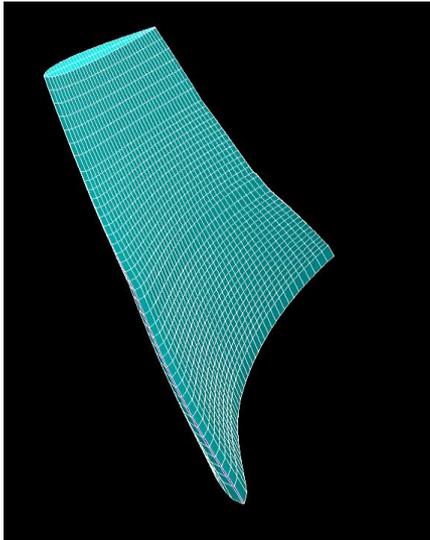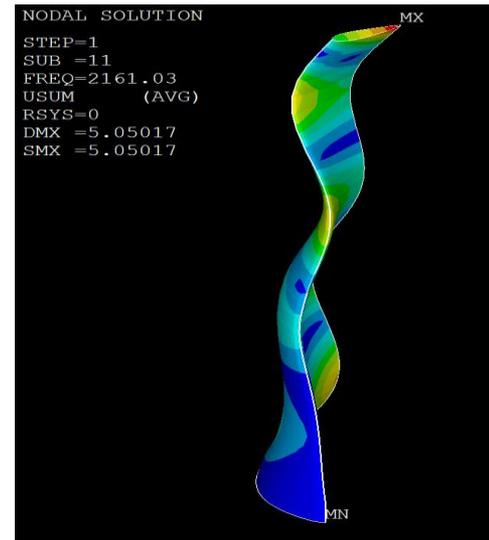

Airfoil Model
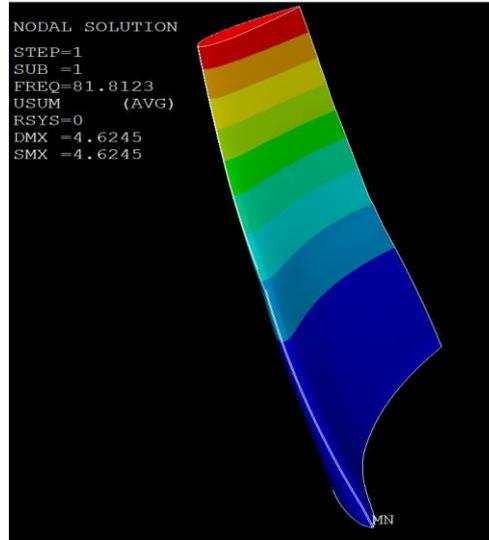
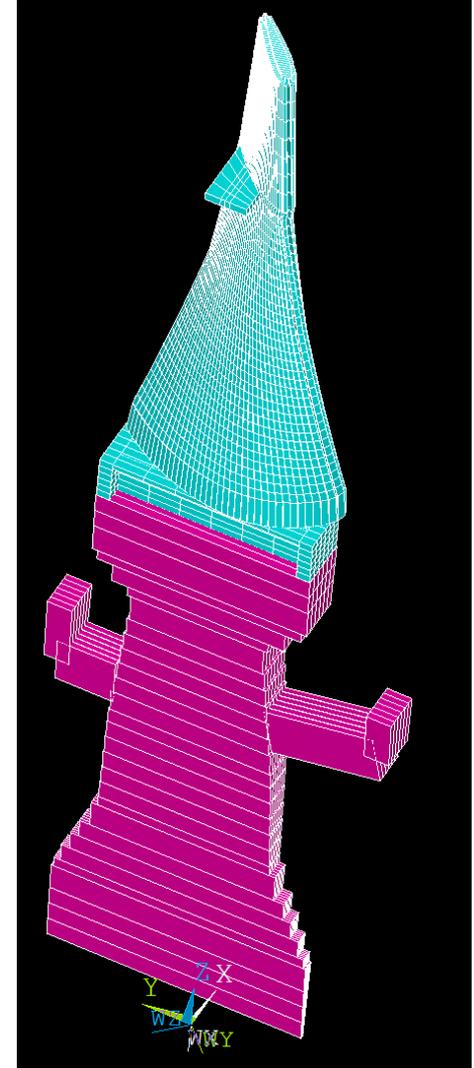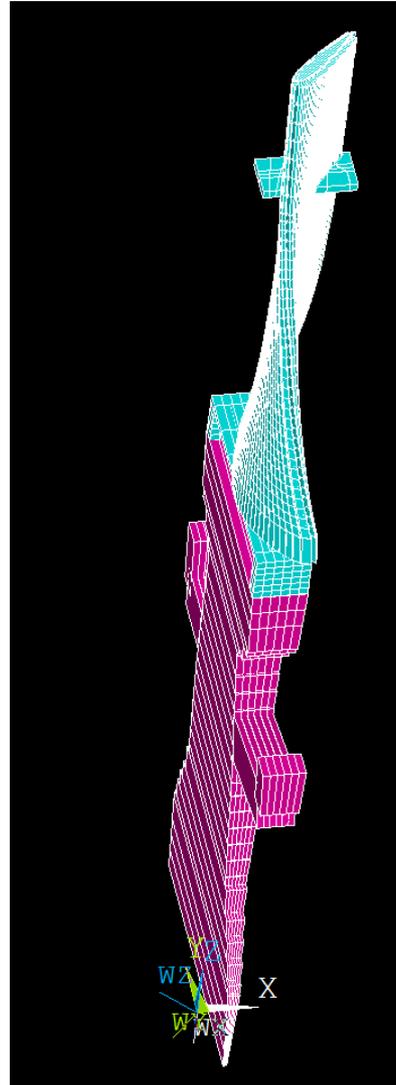

1st Axial
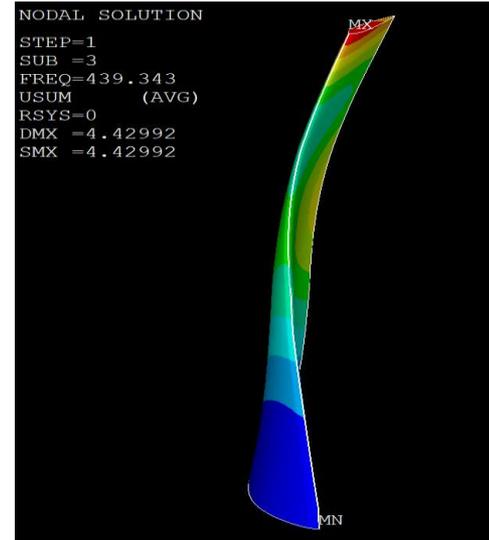
1st Flex
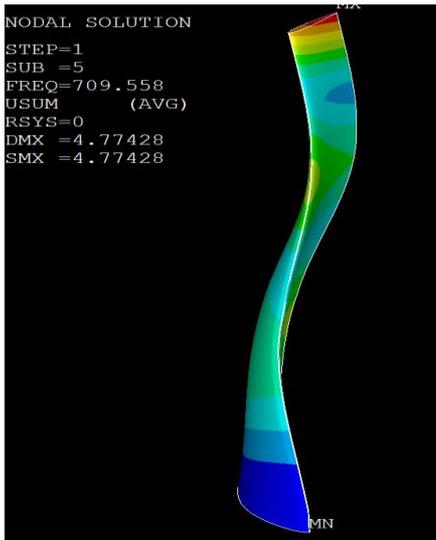
Mode 5
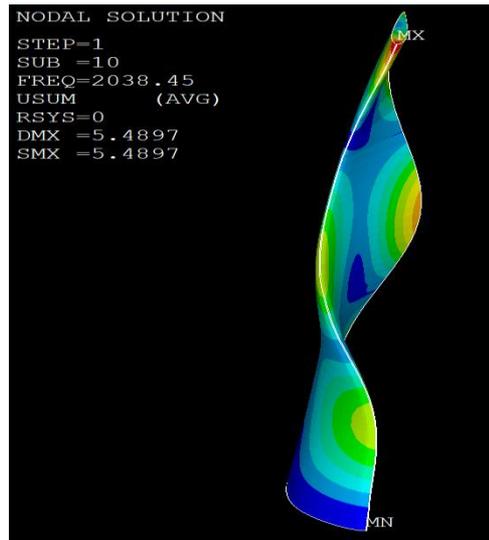
Mode 10

Mode 11

PS/SS Airfoil

- Original Airfoil has 1560 elements

- whereas the PS/SS Airfoil has 3200 elements since it contains 2 sections, both comprised of (SHELL181)

- Can look at both SS and PS separately for pressure loading

DOE input

- Kept Constant RPM at 3600 and 30 modes per index

- To Validate Model, will analyze High Frequency Modes and see if they match with the original model

Default Parameters

Mass Values and Run Time

- Ran a Macro Script to fix all Nodes at its current location and calculate all mass/volume in the elements

- Values for both Camber and PS/SS models had the same exact value for total mass, center of mass, and moment of inertia

- Computational Run Time for Original Code was 14:10:52 to 14:19:29 which is 8 min 37 seconds

- Computational Run Time for New Code was 13:35:53 to 13:44:33 which is 8 min 30 seconds

- Computation Time for both codes are almost identical, New Code builds elements from PS/SS rather than having to build them from the Camber Line which takes longer to build due to the hollow section that it is building along the ribs

```
**** CENTER OF MASS, MASS, AND MASS MOMENTS OF INERTIA ****

CALCULATIONS ASSUME ELEMENT MASS AT ELEMENT CENTROID

TOTAL MASS =  0.90253

                              MOM. OF INERTIA        MOM. OF INERTIA
CENTER OF MASS                ABOUT ORIGIN           ABOUT CENTER OF MASS

XC = -0.39883E-01     IXX =    660.3        IXX =     110.1
YC =  0.64553         IYY =    656.1        IYY =     106.3
ZC =    24.683        IZZ =    4.947        IZZ =     4.570
                      IXY = -0.5433E-01     IXY = -0.7756E-01
                      IYZ =   -13.78        IYZ =    0.5971
                      IZX =    1.587        IZX =    0.6983
```

Modal Analysis
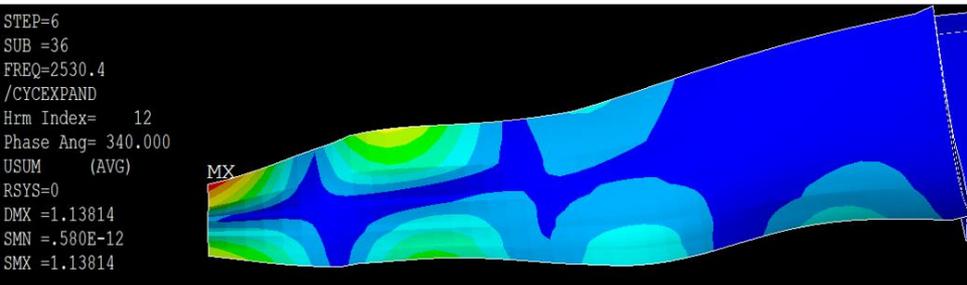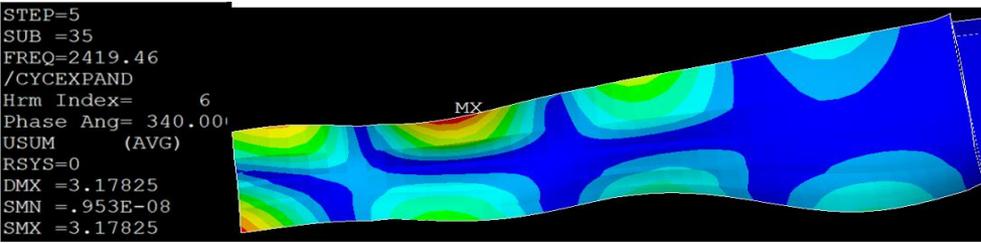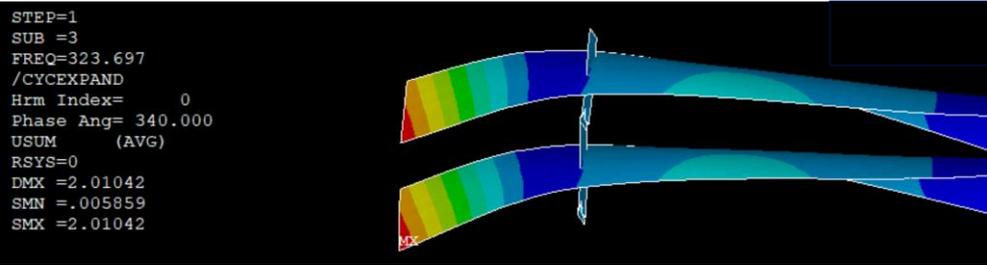
Camber Model   PS/SS Model
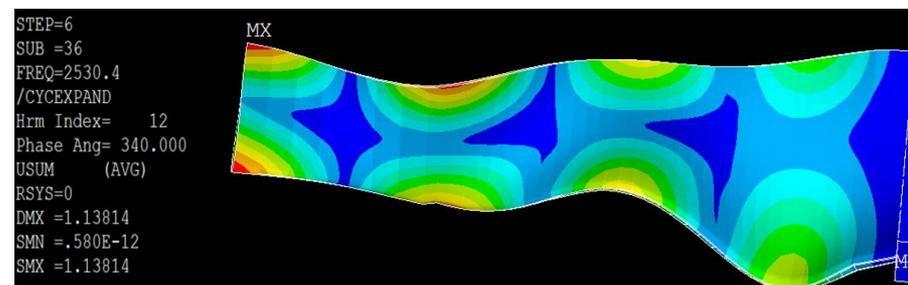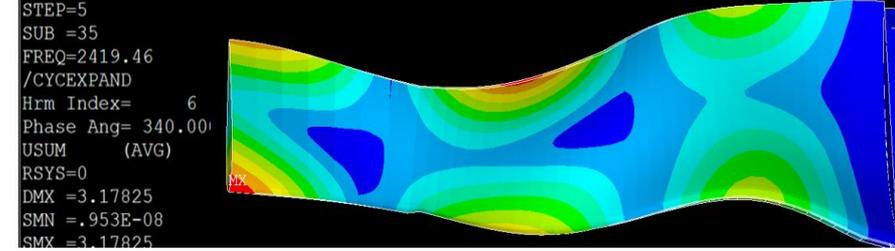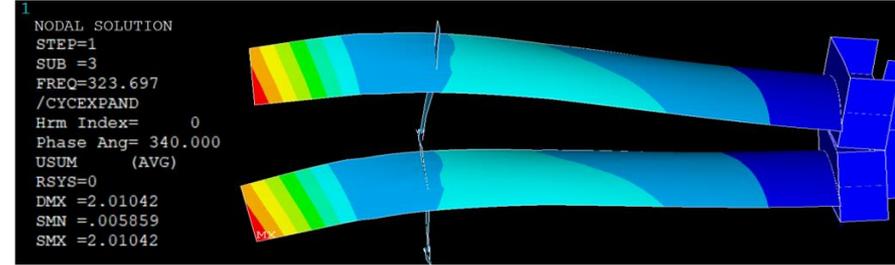
Frequency Values

- With the same constraints equations applied to both models, the frequency values for most subsets were identical or very close to each other

- Possible deviation in modal plots due to Node displacement, Constraint Equations, and Shroud placement but still works as a good baseline case for Validation, need future study and development to improve it further.

Frequency Values of Surya's and My Model

SET	TIME/FREQ (Surya)	TIME/FREQ (Abhi)	LOAD STEP	SUBSTEP	CUMULATIVE	HRM-INDEX
1	120.31	120.31	1	1	1	0
2	227.41	227.41	1	2	2	0
3	323.70	323.70	1	3	3	0
4	486.72	486.72	1	4	4	0
5	595.05	595.05	1	5	5	0
6	621.89	621.89	1	6	6	0
7	706.29	706.29	1	7	7	0
8	797.09	786.47	1	8	8	0
9	826.43	846.81	1	9	9	0
10	1066.2	1066.2	1	10	10	0
11	1161.3	1161.3	1	11	11	0
12	1333.1	1333.1	1	12	12	0
13	1476.9	1441.1	1	13	13	0
14	1502.7	1502.7	1	14	14	0
15	1670.9	1670.9	1	15	15	0
16	1862.4	1792.8	1	16	16	0
17	1892.4	1892.4	1	17	17	0
18	1907.9	1907.9	1	18	18	0
19	2035.4	2050.9	1	19	19	0
20	2128.9	2128.9	1	20	20	0
21	2260.9	2260.9	1	21	21	0
22	2340.6	2340.6	1	22	22	0
23	2395.9	2395.9	1	23	23	0
24	2548.3	2548.3	1	24	24	0
25	2582.6	2582.6	1	25	25	0
26	2615.7	2615.7	1	26	26	0
27	2737.2	2737.2	1	27	27	0
28	2837.2	2837.2	1	28	28	0
29	2873.7	2873.7	1	29	29	0
30	2943.3	2943.3	1	30	30	0

Future Considerations

- Due to time constraints for learning and debugging Code with subroutines, one thing to recommend to improve this internship is to provide training with more detailed documentation of Code and Diagrams to teach future interns and engineers

- To help aid that process, I created a documented chart of the BLAST code with all sections of code detailed

- Recommend newer/powerful engineering laptops for future interns, they were adequate this summer but felt slow and could not process files during some parts of the day

Overall Experiences

- Networked with numerous skilled engineers and met multiple interns which made office environment enjoyable to work in

- Improved my analytical and communicative skills

- Learned more Computation skills and software such as ANSYS, NX, Macro Scripting, and MATLAB

- Fully enjoyed my full 13-week internship

Questions?