MAE – 573 APPLICATIONS OF FINITE ELEMENT ANALYSIS

PROJECT – THERMO MECHANICAL ANALYSIS OF A COMPUTER COOLING SYSTEM

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PROBLEM DEFINITION:

- This model represents a Thermo-Mechanical analysis of a computer cooling system.

- The goal of this project is to run the simulation in ANSYS WORKBENCH and find the following:

  - Temperature and heat flux for the whole system and each individual component.

  - The von-mises stress and total deformation for the whole system and individual component.

  - The von mises stresses, total deformation, radial deformation, and safety factor for a 1/7th sector of the fan blade.

  - A modal analysis including the first 6 natural frequencies and mode shape for the fan component only and its graph.

  - To find structural and parametric analysis of the fan component only.

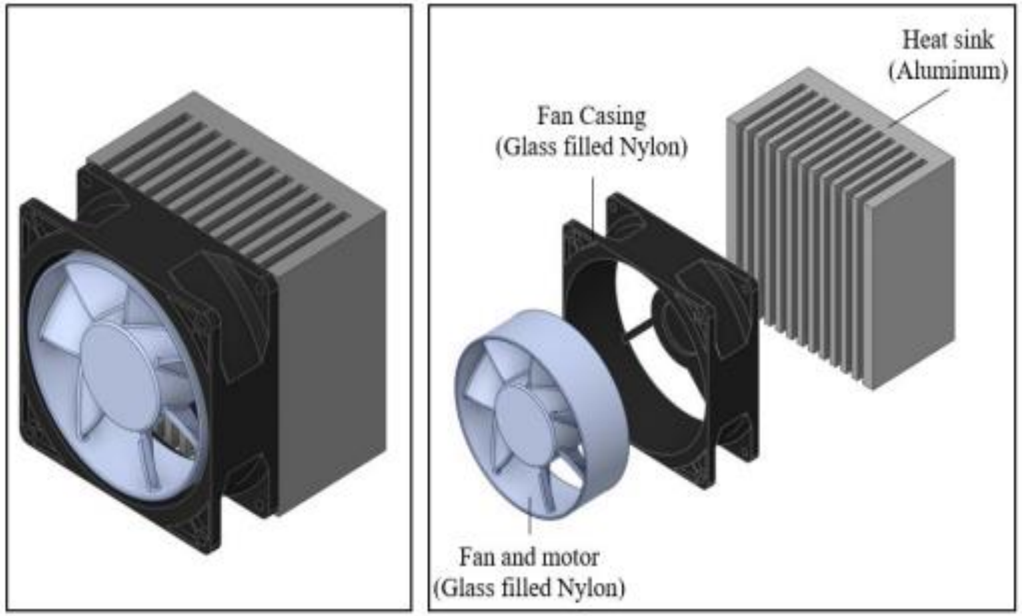


Fig A: Model of the component.

MATERIAL PROPERTIES OF THE GLASS - FILLED NYLON & ALUMINIUM ALLOY :

Glass - filled Nylon

Density	1360 kg/m^3

Structural

Isotropic Elasticity	
Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	6.2e+09 Pa
Poisson's Ratio	0.35
Bulk Modulus	6.8889e+09 Pa
Shear Modulus	2.2963e+09 Pa
Isotropic Secant Coefficient of Thermal Expansion	2.56e-05 1/°C
Compressive Yield Strength	5.5e+07 Pa
Tensile Yield Strength	5.5e+07 Pa

Thermal

Isotropic Thermal Conductivity	0.23 W/m·°C

Fig B: Material properties of the glass – filled nylon

Aluminum - Heat Sink

General aluminum alloy. Fatigue properties come from MIL-HDBK-5H, page 3-277.

Density	2700 kg/m^3

Structural

Isotropic Elasticity	
Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	6.98e+10 Pa
Poisson's Ratio	0.33
Bulk Modulus	6.8431e+10 Pa
Shear Modulus	2.6241e+10 Pa
Isotropic Secant Coefficient of Thermal Expansion	2.36e-05 1/°C
Compressive Yield Strength	2.76e+08 Pa
Tensile Yield Strength	2.76e+08 Pa

Thermal

Isotropic Thermal Conductivity	167 W/m·°C

Fig C: Material properties of the Aluminum - Heat Sink

GEOMETRY & MESH OF THE ENTIRE FAN SYSTEM:

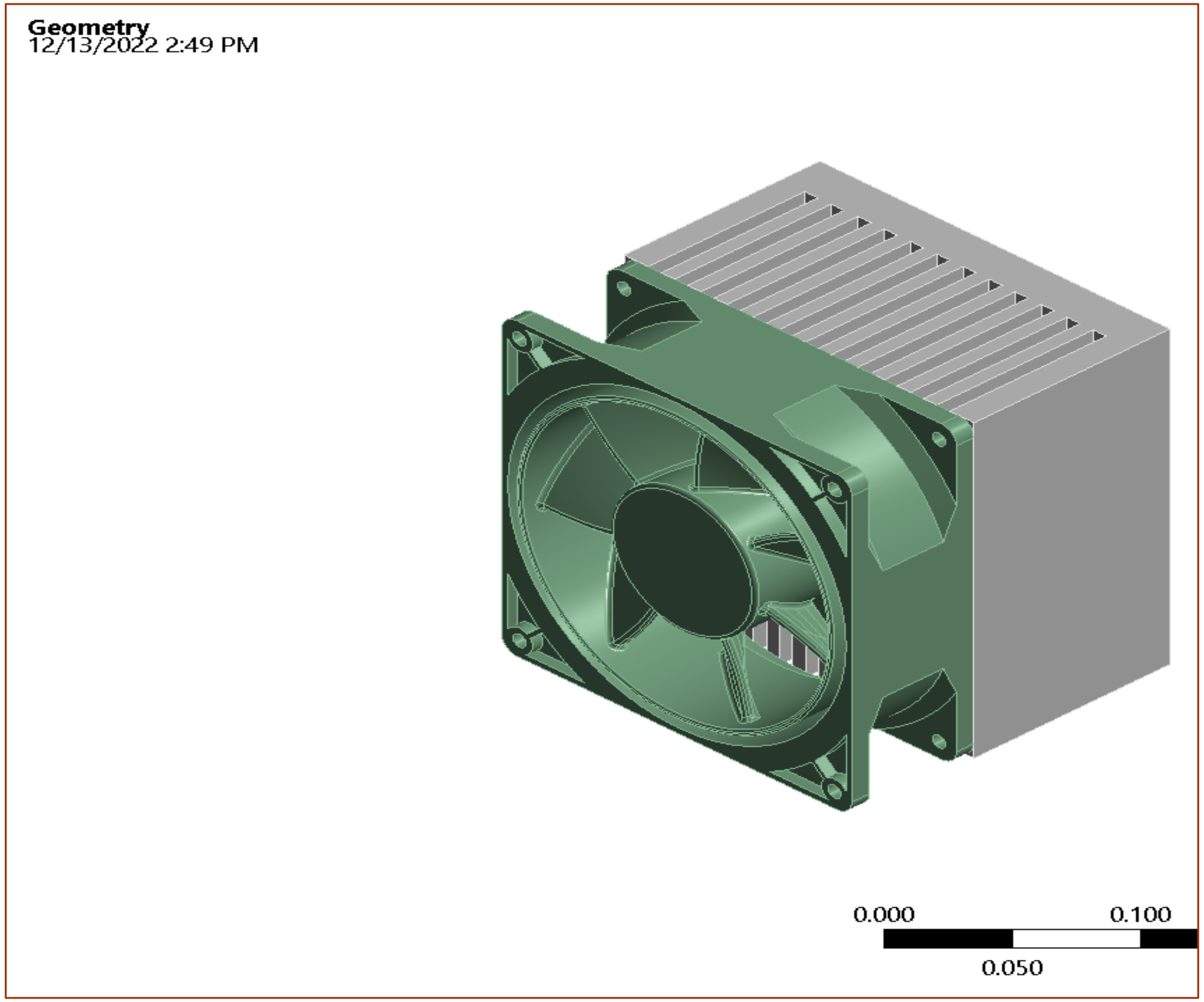


Fig D: Geometry of the entire fan system

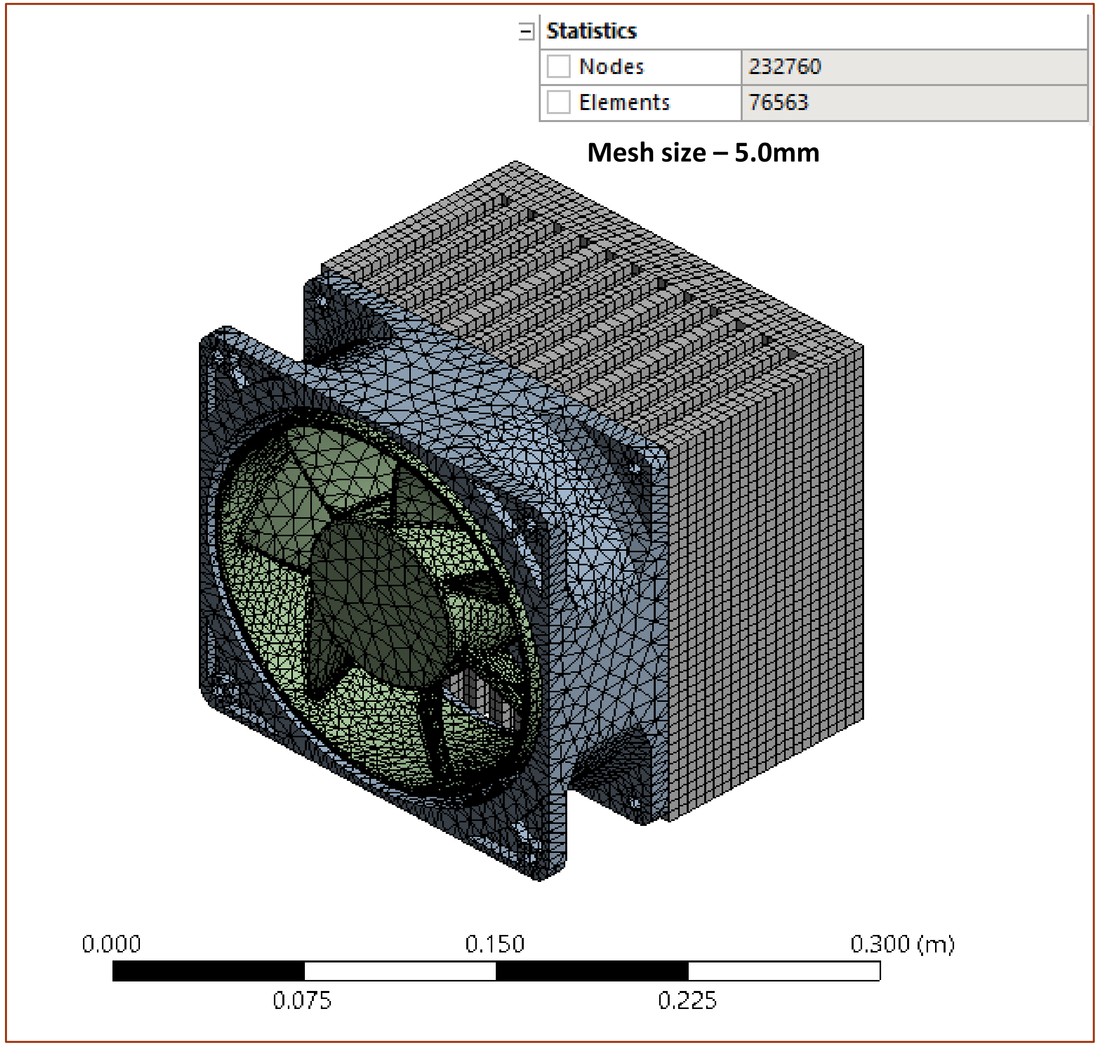
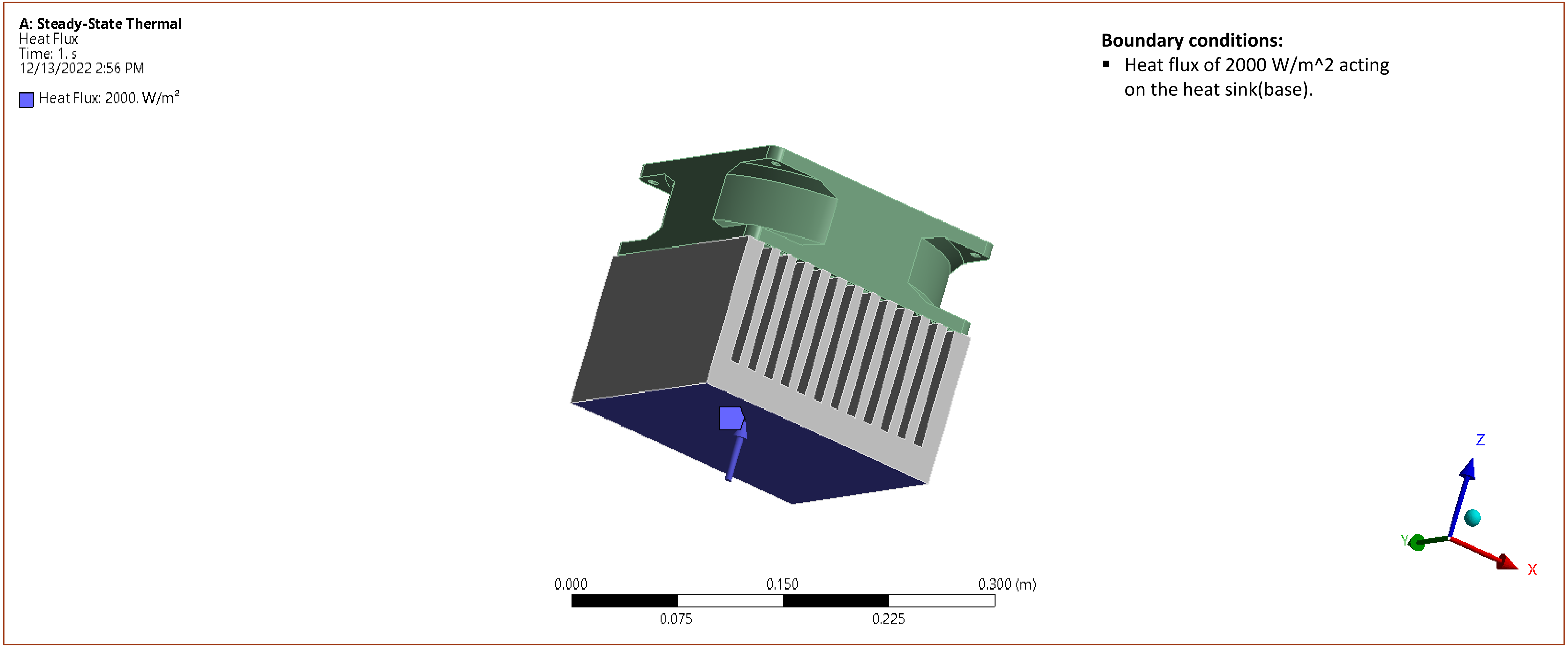


Fig E: Mesh of the entire fan system

PART 1: THERMO- STRUCTURAL ANALYSIS OF THE ENTIRE FAN SYSTEM

BOUNDARY CONDITIONS FOR THERMAL ANALYSIS:

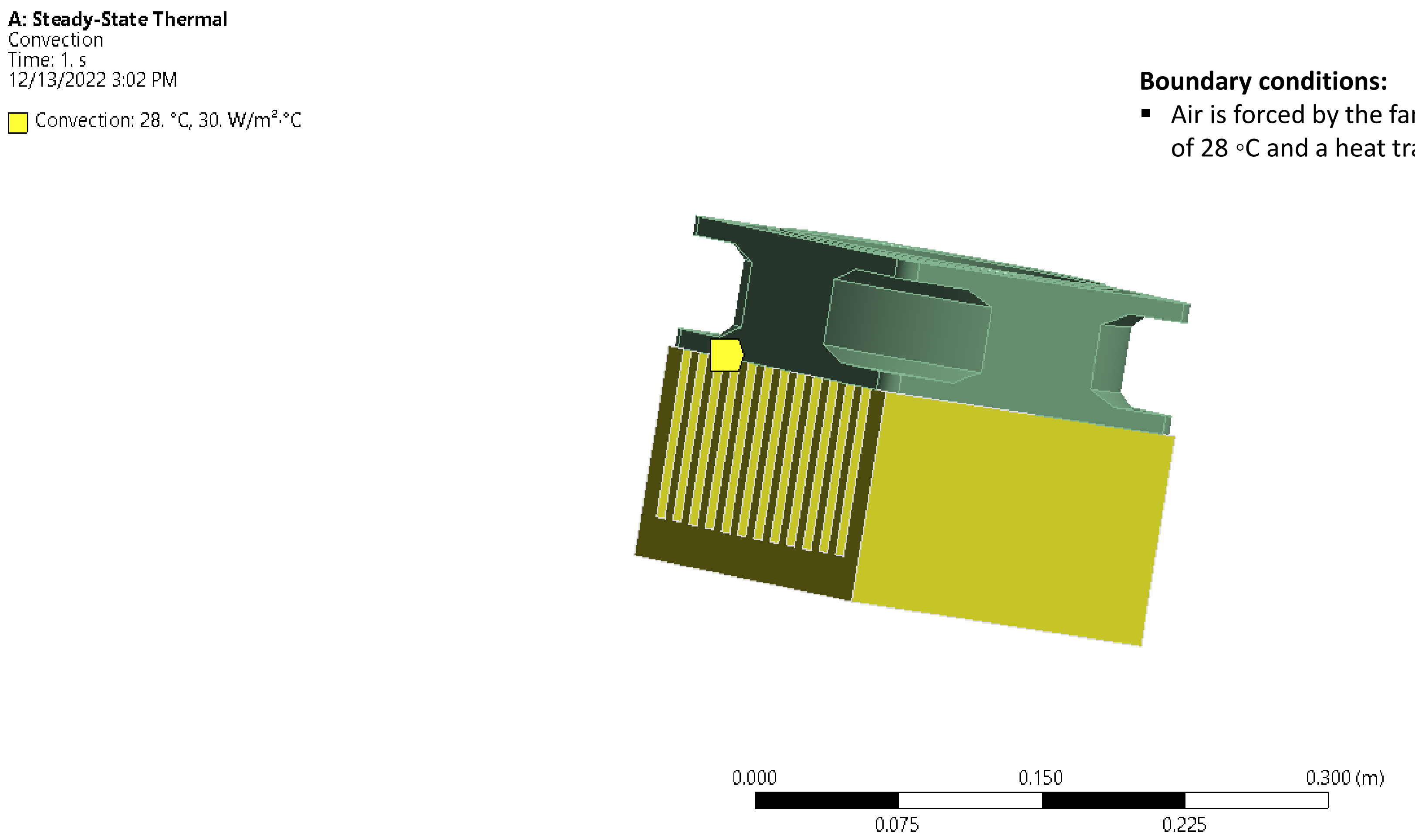


Boundary conditions:

- Heat flux of 2000 W/m^2 acting on the heat sink(base).

Fig F: Boundary condition imposed on heat sink (Base)

BOUNDARY CONDITIONS FOR THERMAL ANALYSIS:



Boundary conditions:

- Air is forced by the fan over the heat sink with the temperature of 28 ◦C and a heat transfer coefficient of h = 30W/(m2◦C).

Fig G:Boundary condition imposed on heat sink with the exemption(base)

CONTOUR PLOT - TEMPERATURE OF WHOLE SYSTEM & FAN:

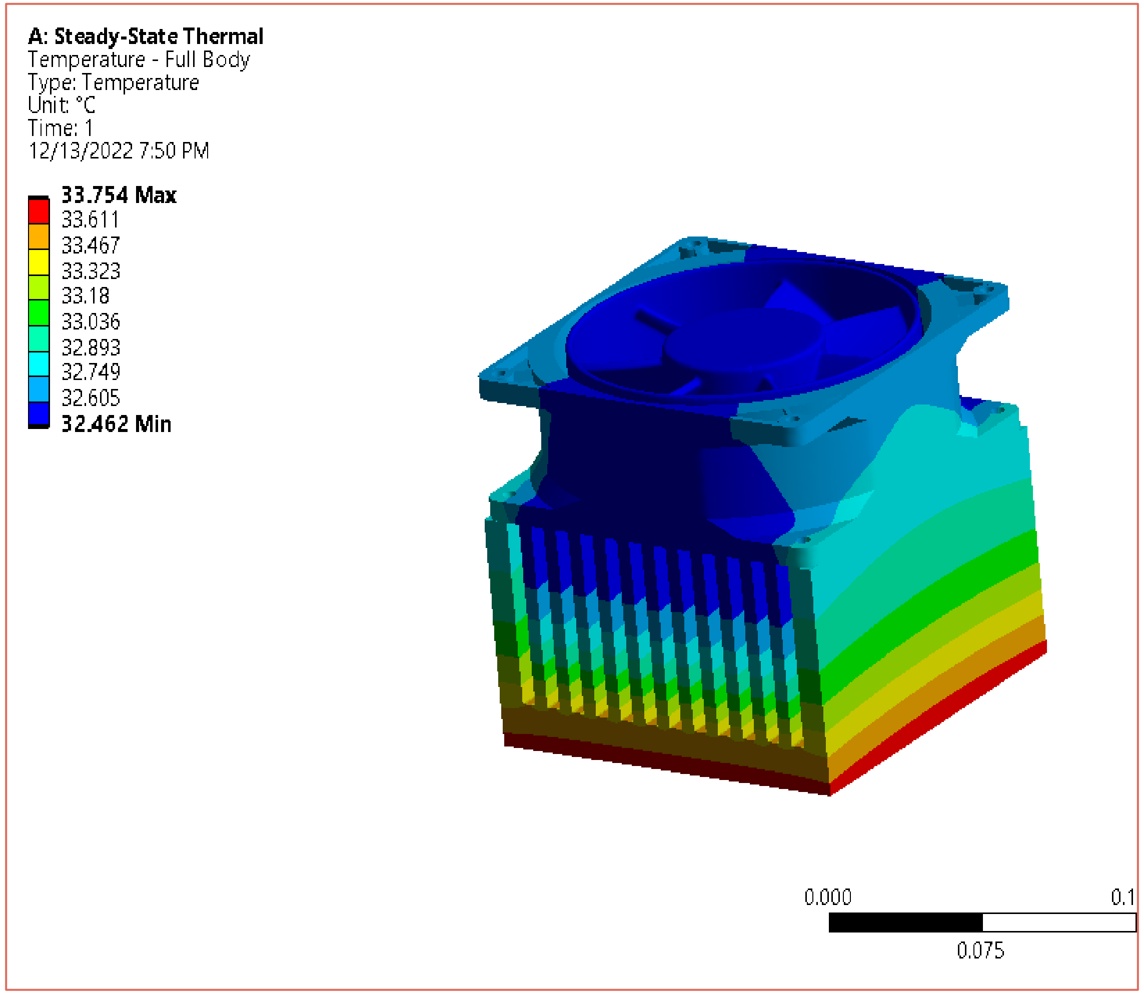


Fig H: Temperature of whole system

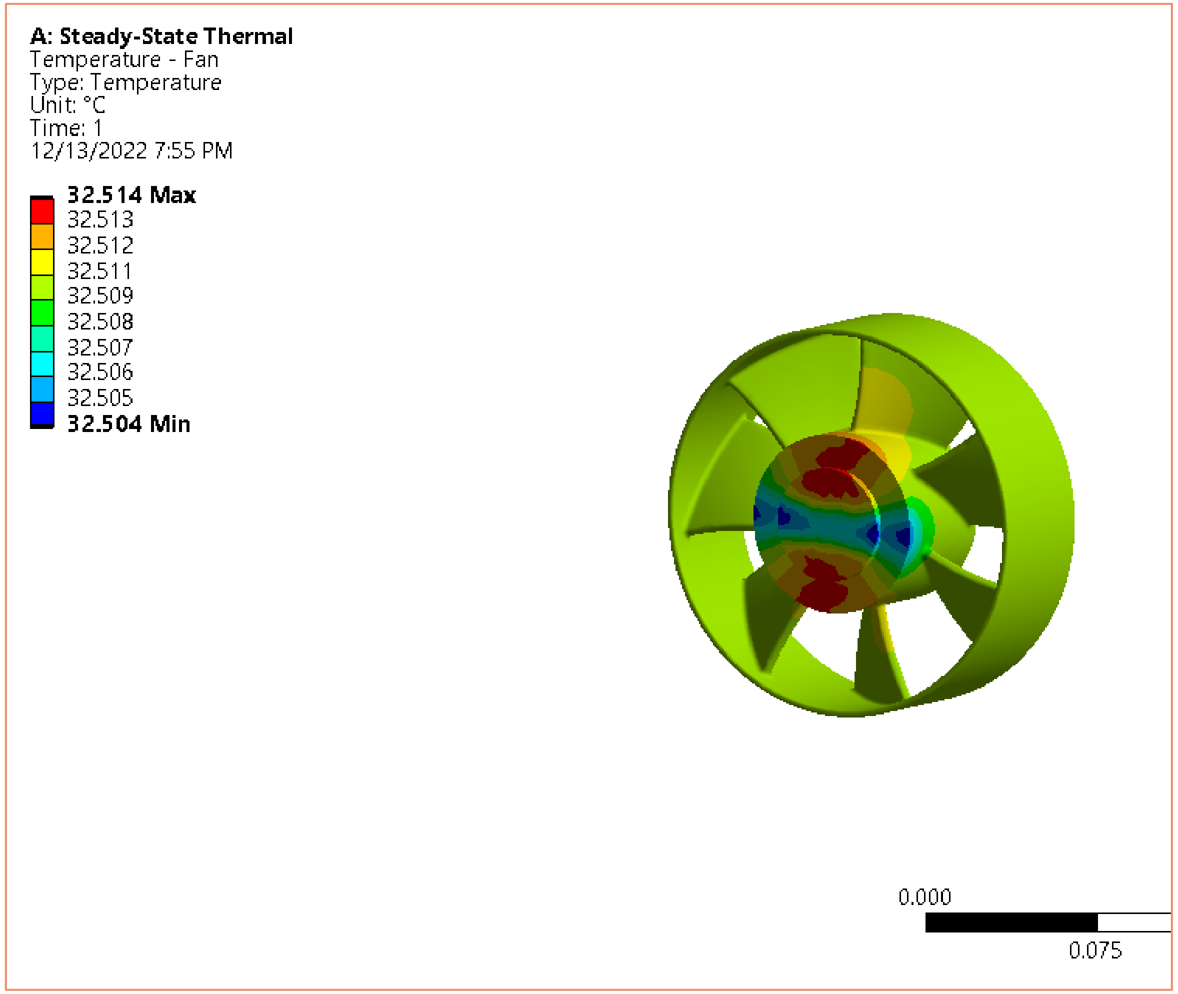


Fig I: Temperature of the fan system

CONTOUR PLOT - TEMPERATURE OF FAN CASING & HEAT SINK:

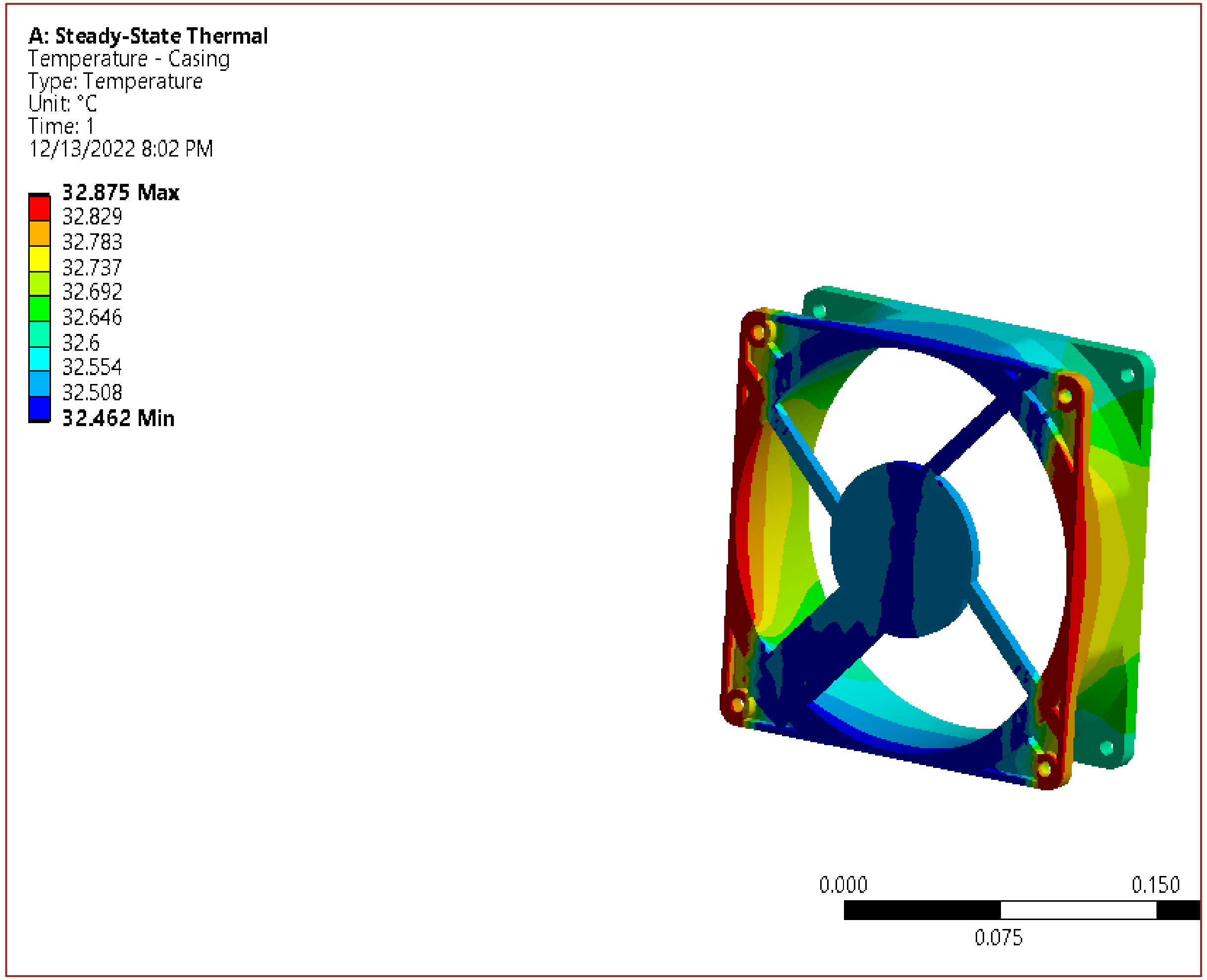


Fig J: Geometry of the fan casing

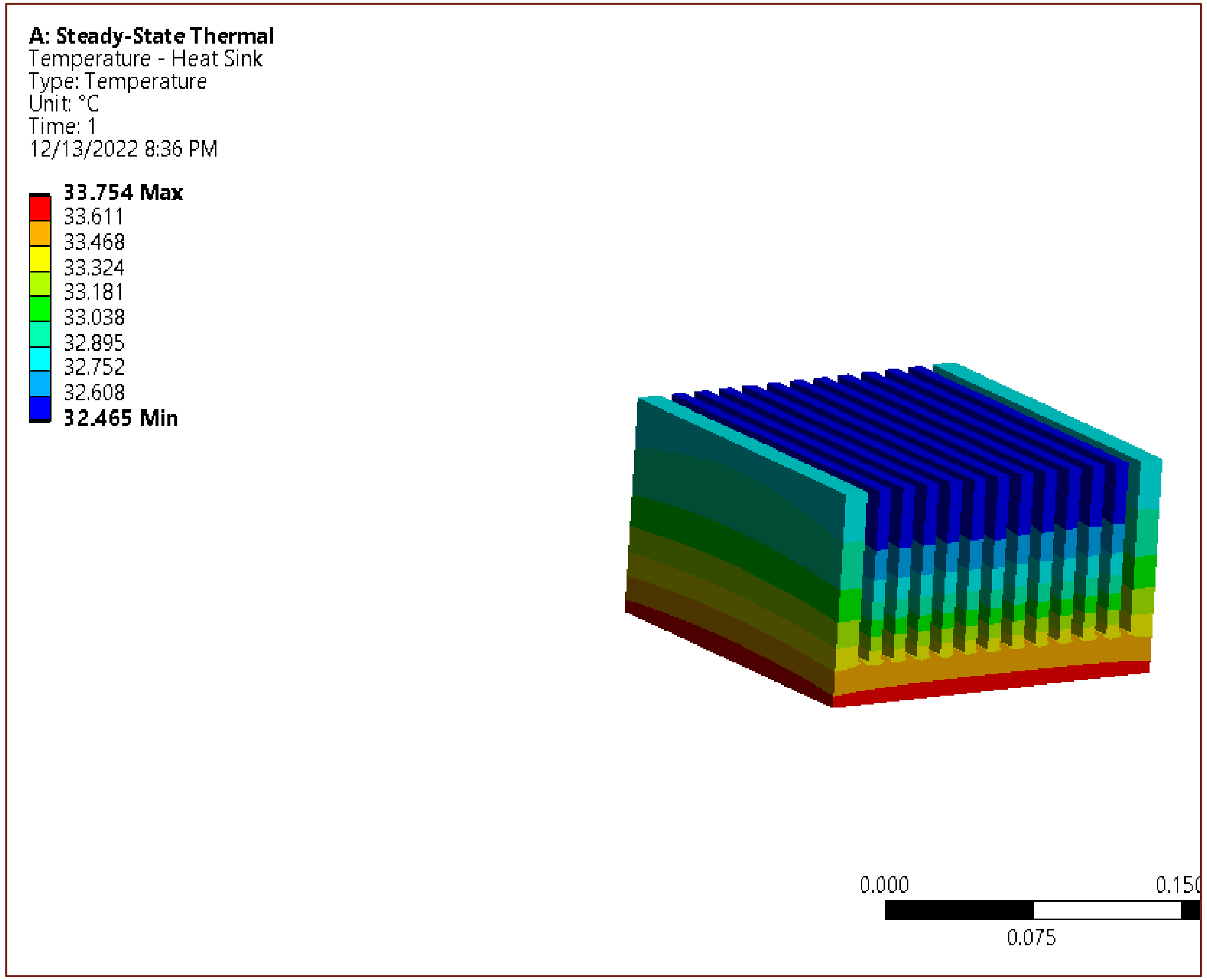


Fig K: Geometry of temperature heat sink

CONTOUR PLOT – HEAT FLUX OF WHOLE SYSTEM & FAN:

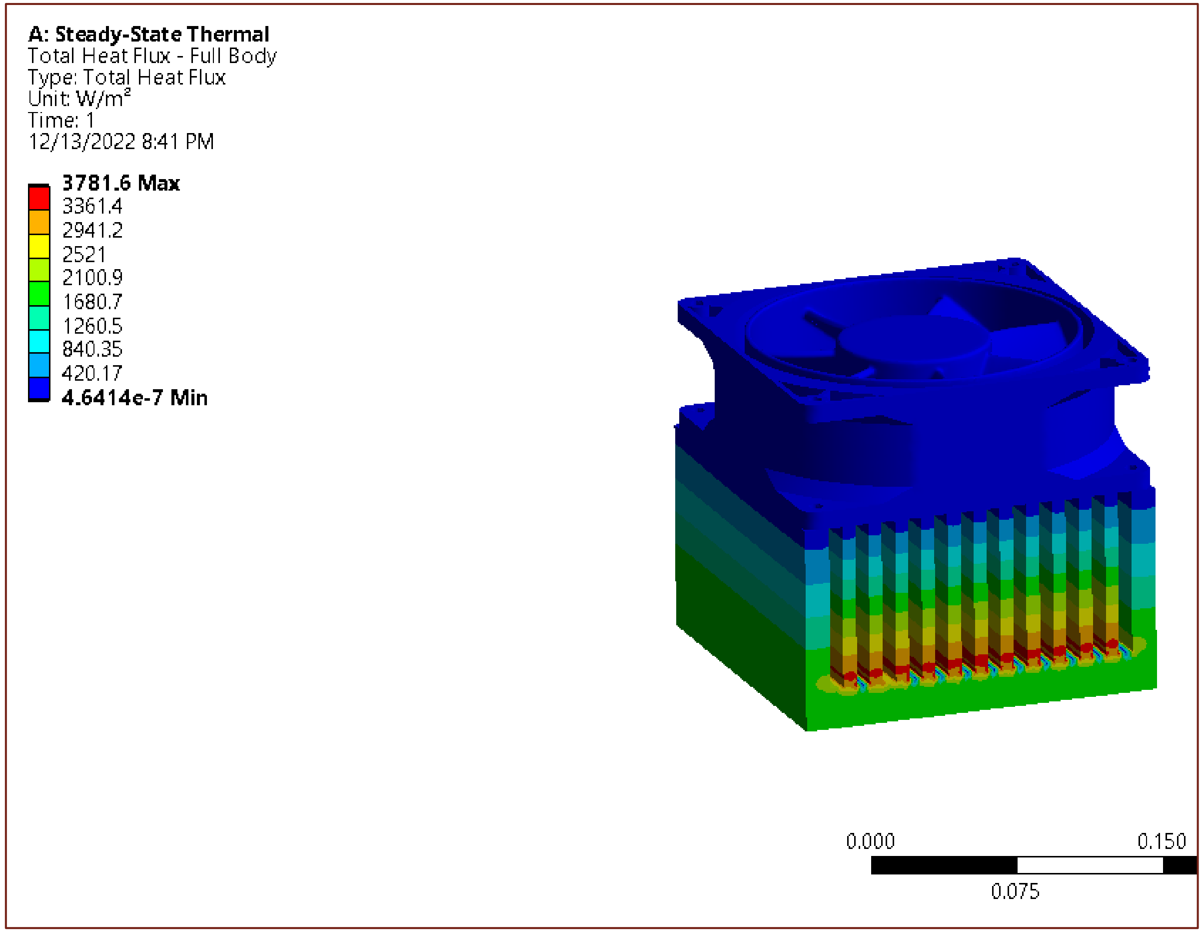


Fig L: Heat flux of the system

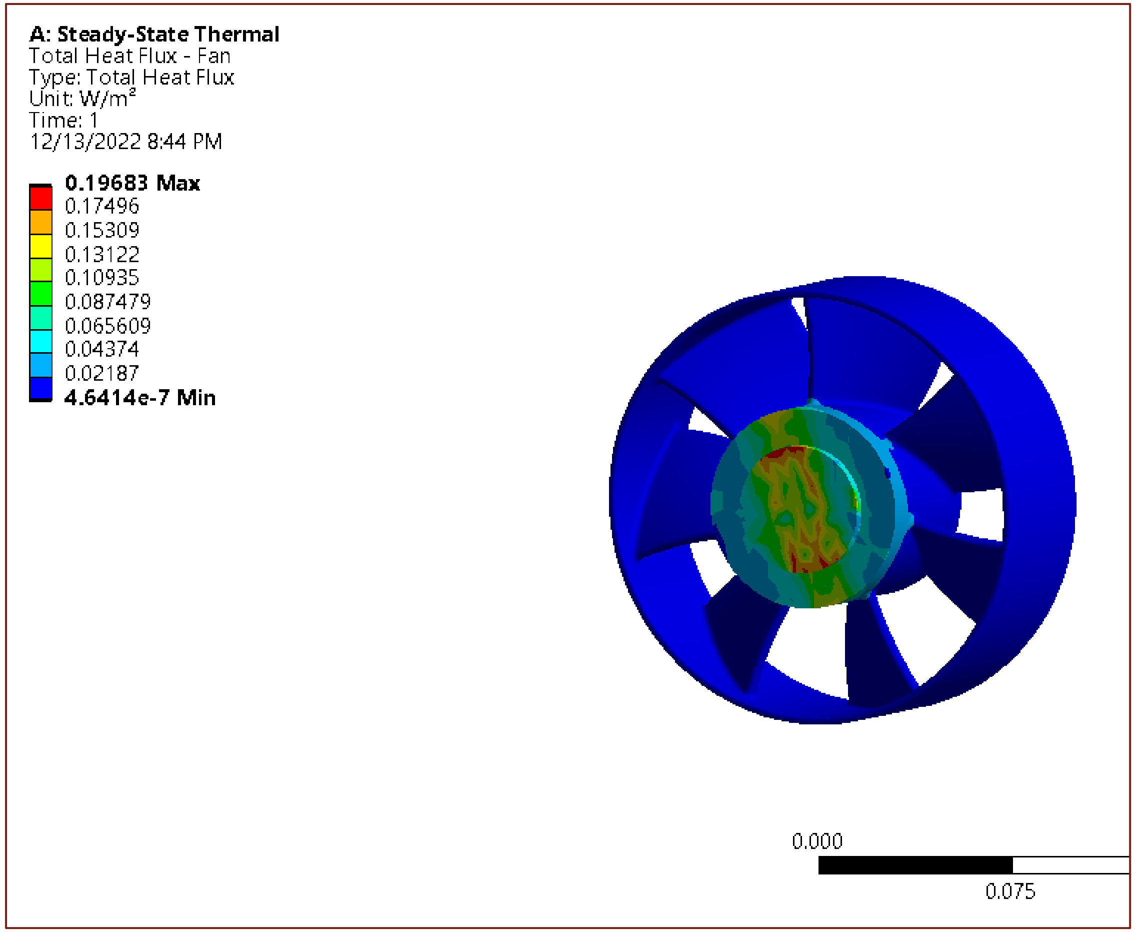


Fig J: Heat flux fan

CONTOUR PLOT - HEAT FLUX OF FAN CASING & HEAT SINK:

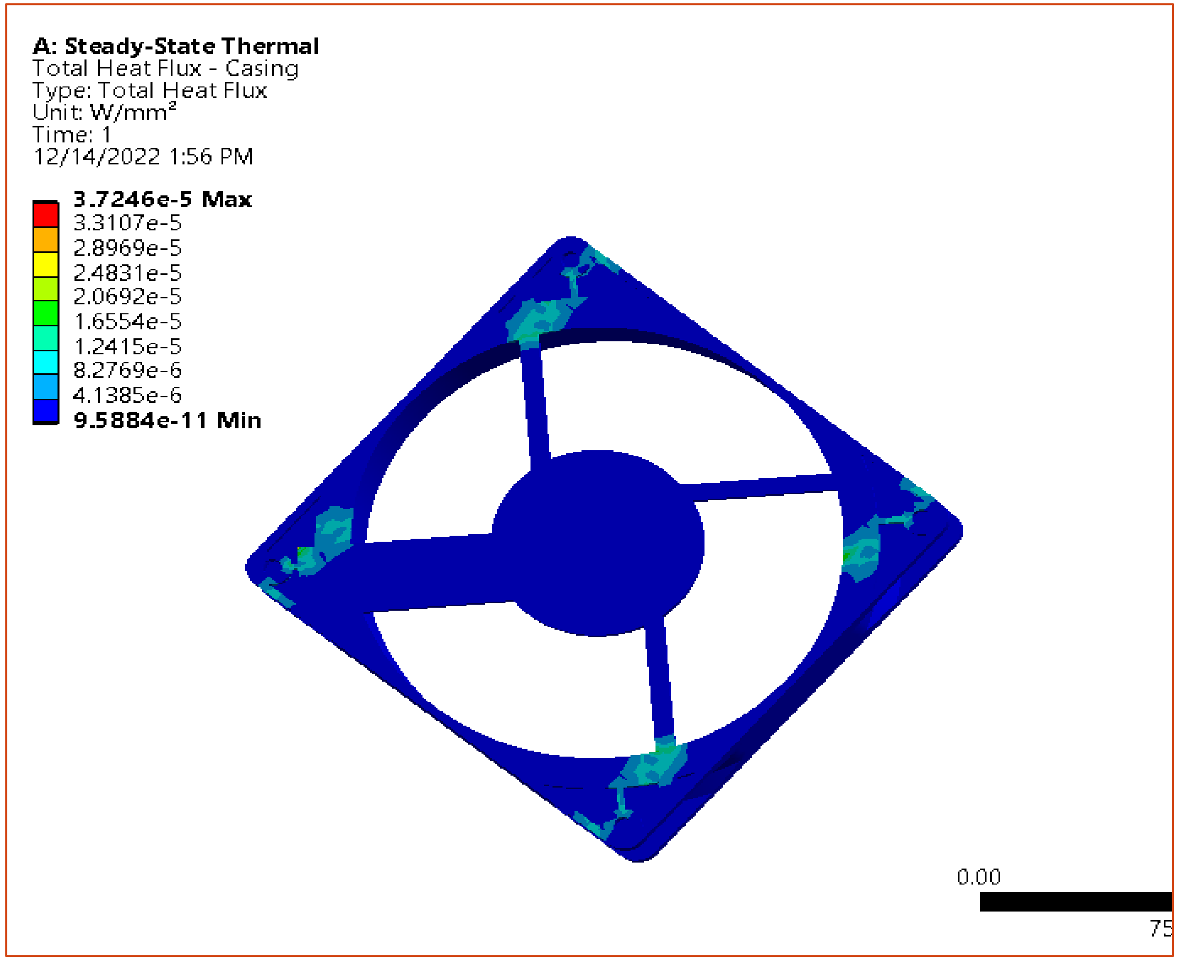


Fig J: Heat flux of the fan casing

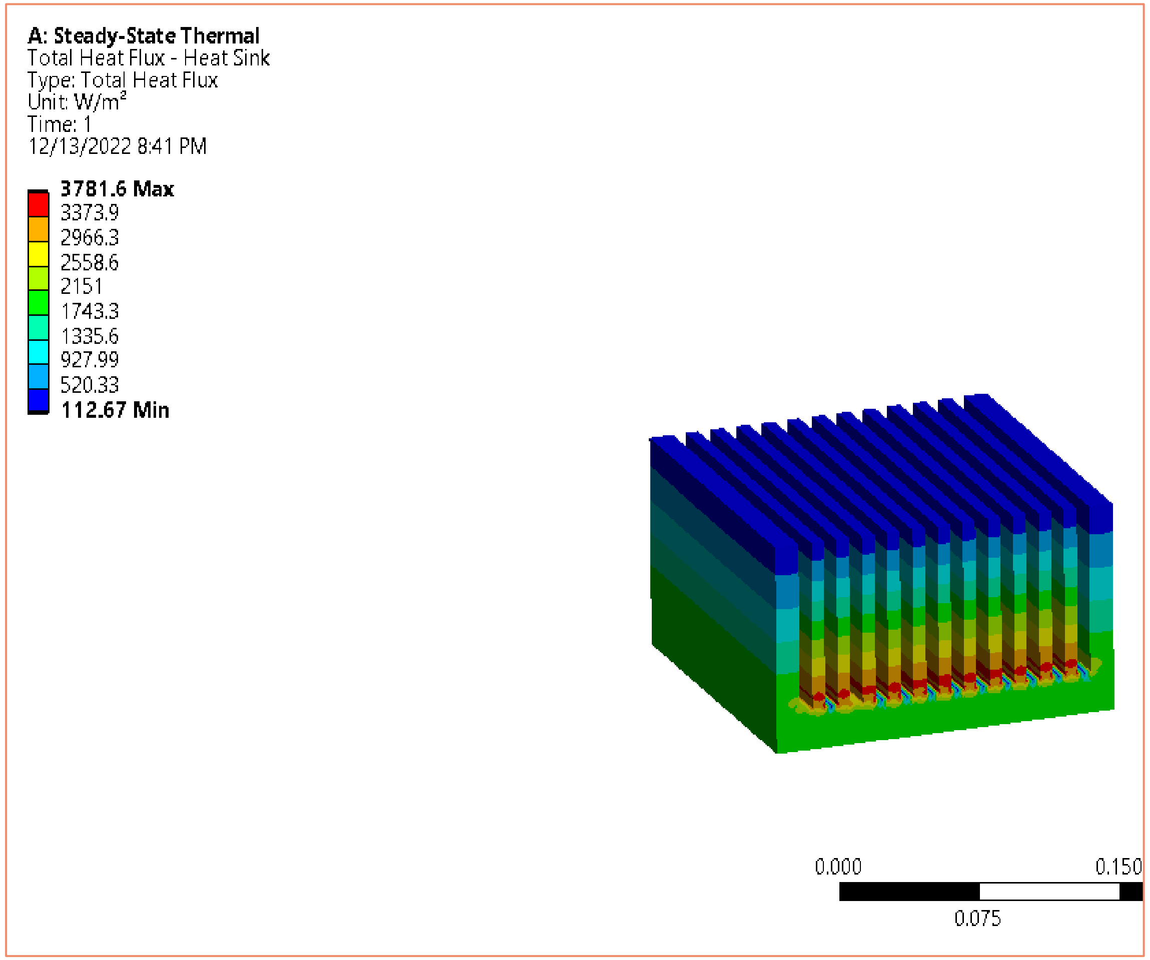


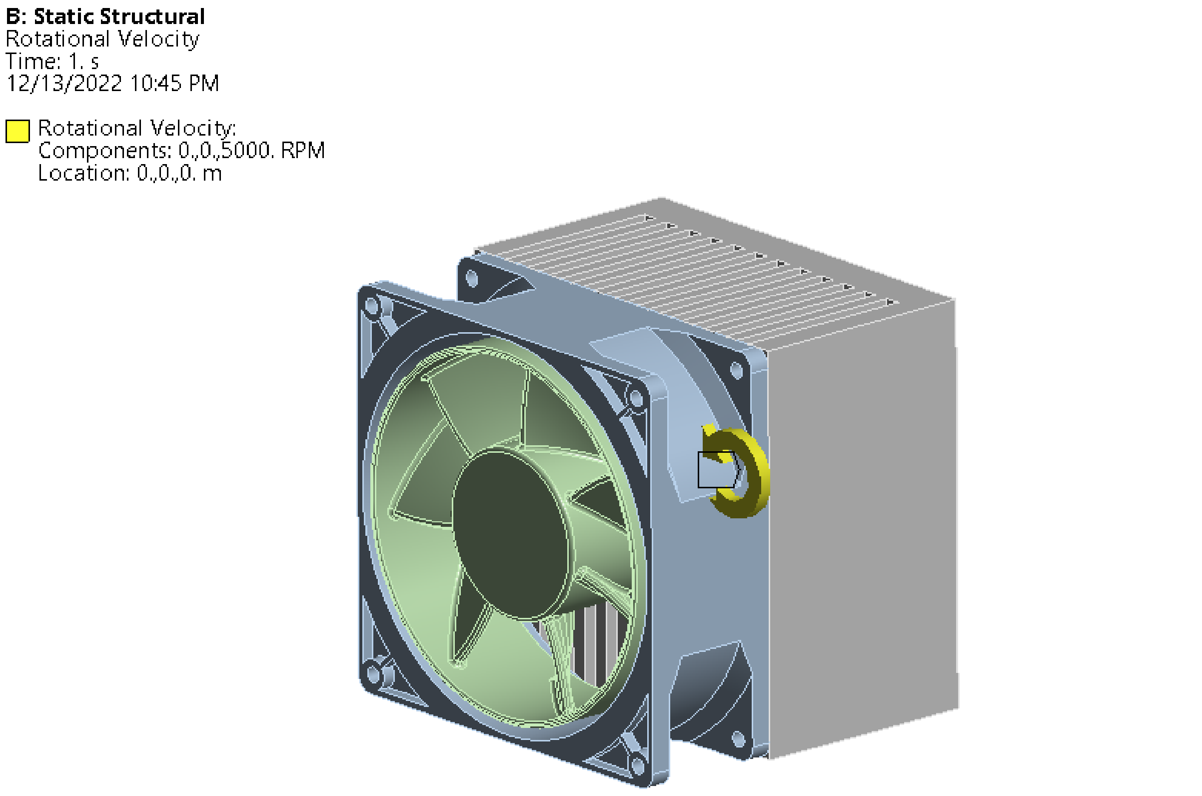
Fig M: Heat sink – Heat flux

DISCUSSION OF HEAT DISSIPATION IN THE GIVEN SYSTEM:

Do you see a quick dissipation of heat (reduction in heat transfer) between the aluminum heat-sink and the plastic casing/fan? If yes, explain the reasons for this heat dissipation.

- We know that aluminum is a very good conductor for the heat.
- From the above simulation, the heat dissipate rapidly between the aluminum and plastic heat sink of the fan section.
- The fact for this is, due to the material which is used for the fan blade and its casing is Glass-filled nylon.
- From the above simulation we can clearly see that the material is very poor conductor of the heat, where the reduction is so drastic in heat transfer once it reaches the edges of the system which is aluminum heat sink.

BOUNDARY CONDITIONS - STRUCTURAL ANALYSIS (ROATIOANL VELOCITY & FIXED SUPPORT)



BOUNDARY CONDITIONS:

- Fan blade rotate at 5000 rpm on z axis with angular velocity.

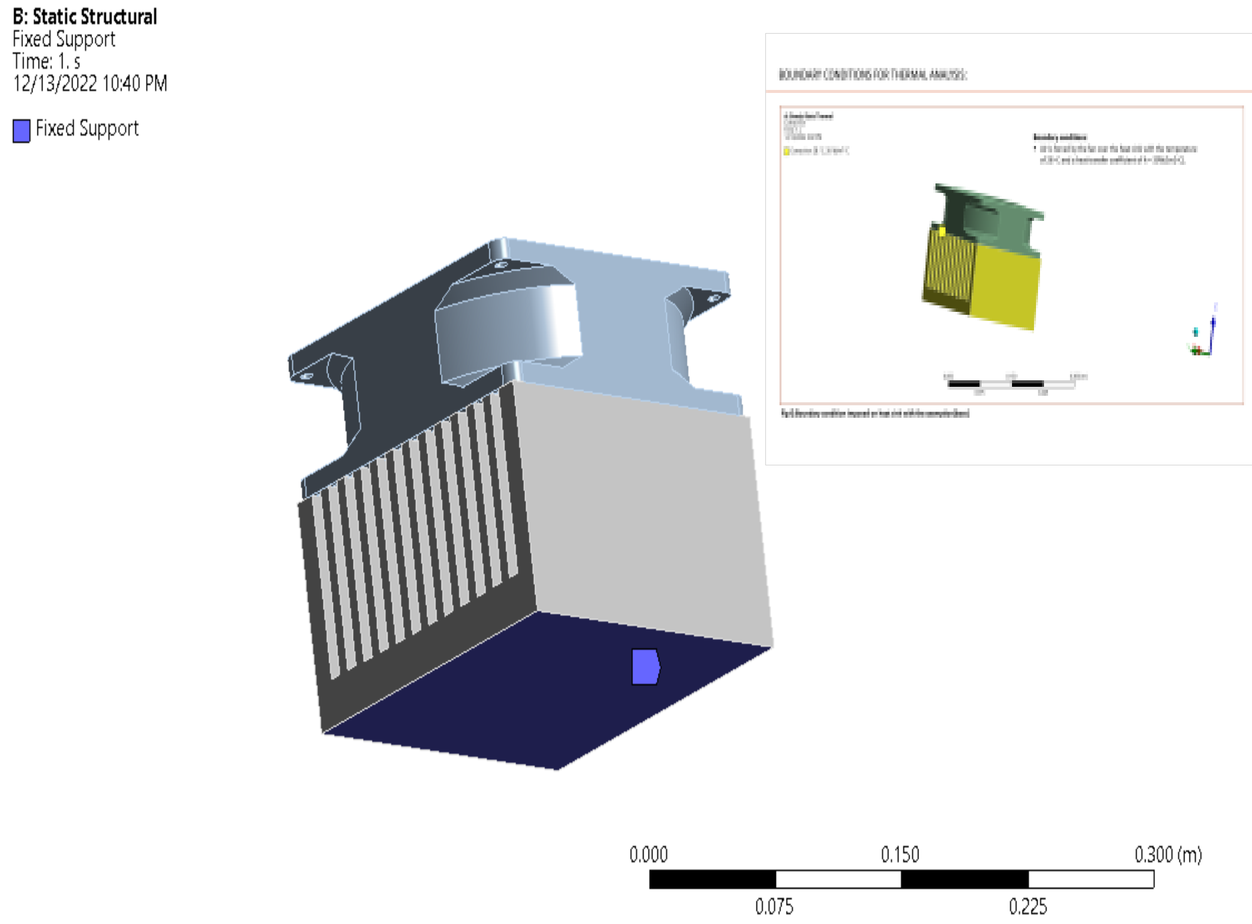


Fig N: Boundary conditions

CONTOUR PLOT – EQUIVALENT STRESS (Von-Mises) OF WHOLE SYSTEM & COOLING FAN:

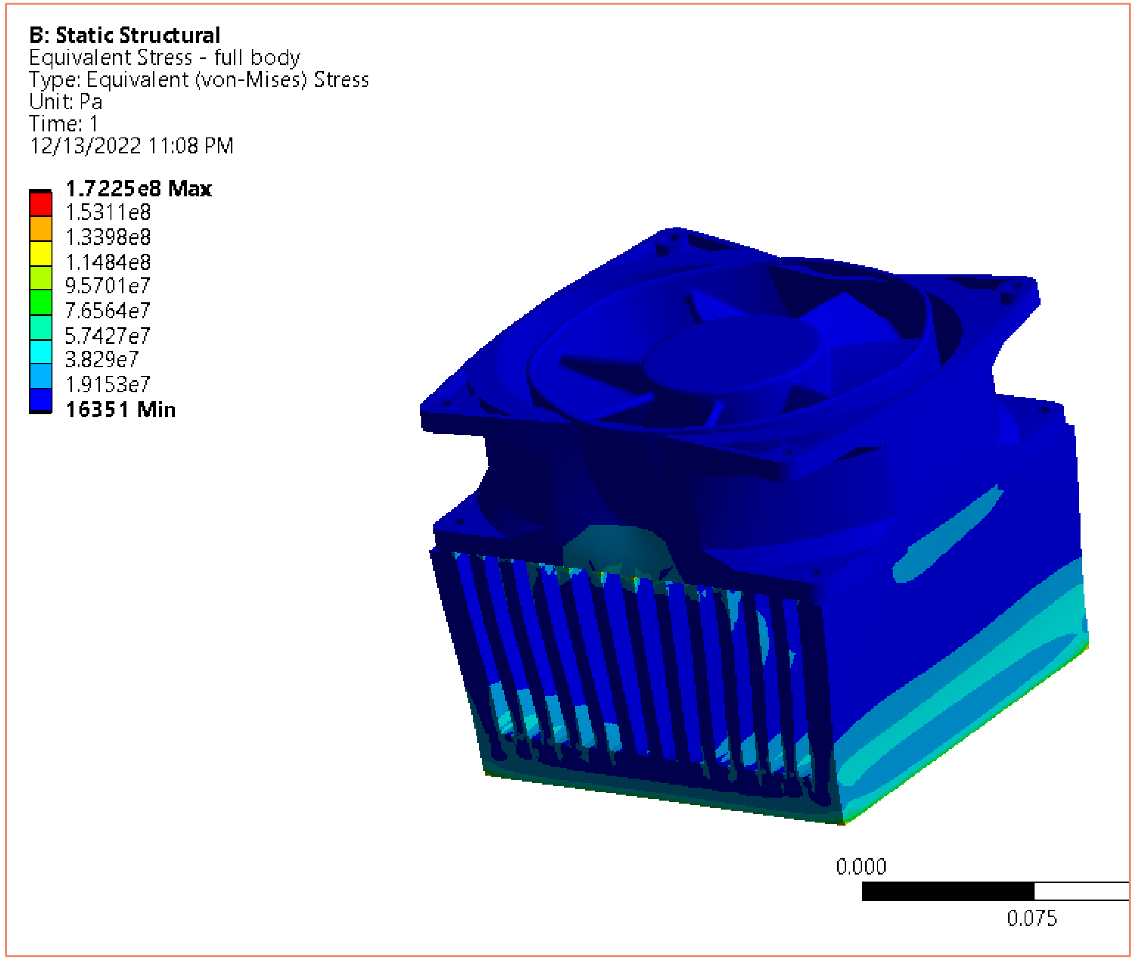


Fig O: Equivalent stress (von-mises) of whole system

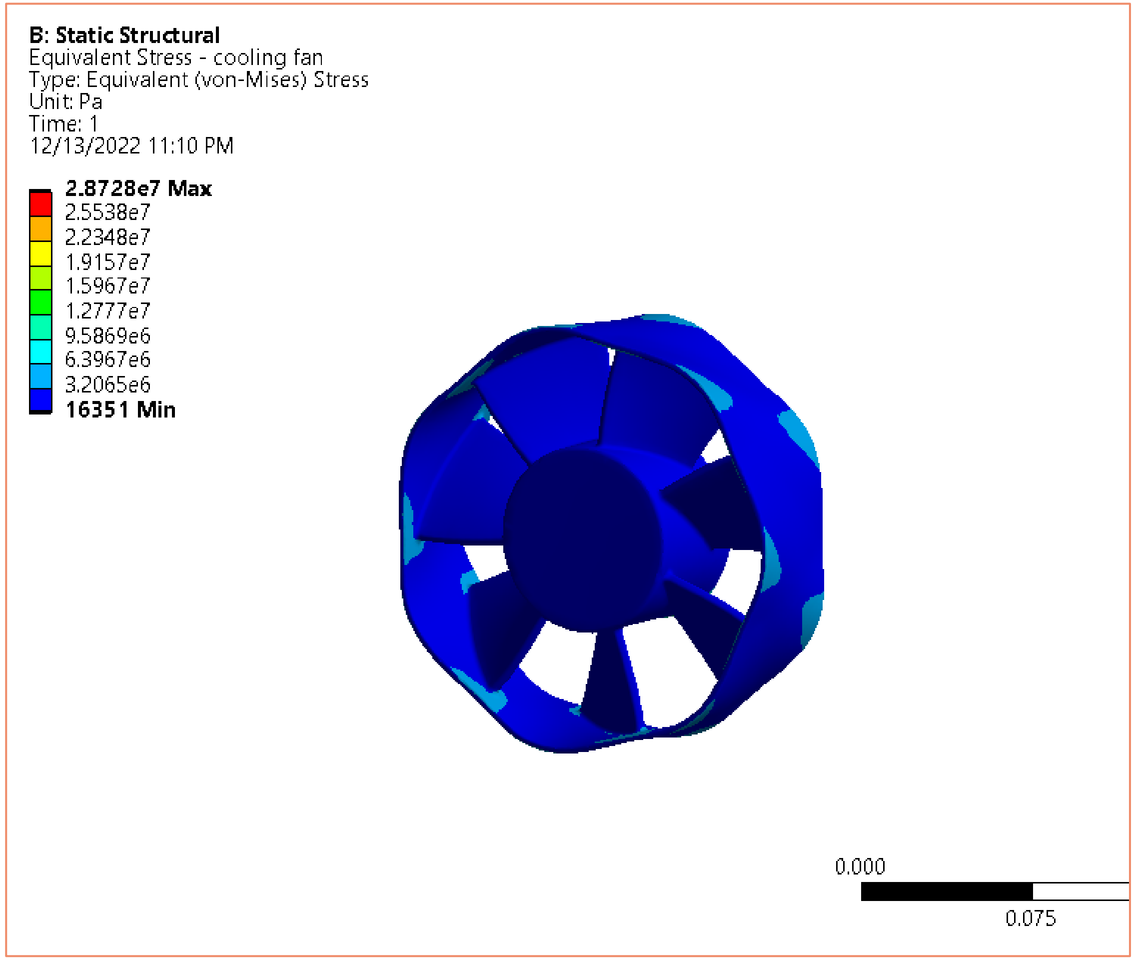


Fig P Equivalent stress (von-mises) of fan

CONTOUR PLOT –EQUIVALENT STRESS (Von-Mises) OF FAN CASING & HEAT SINK:

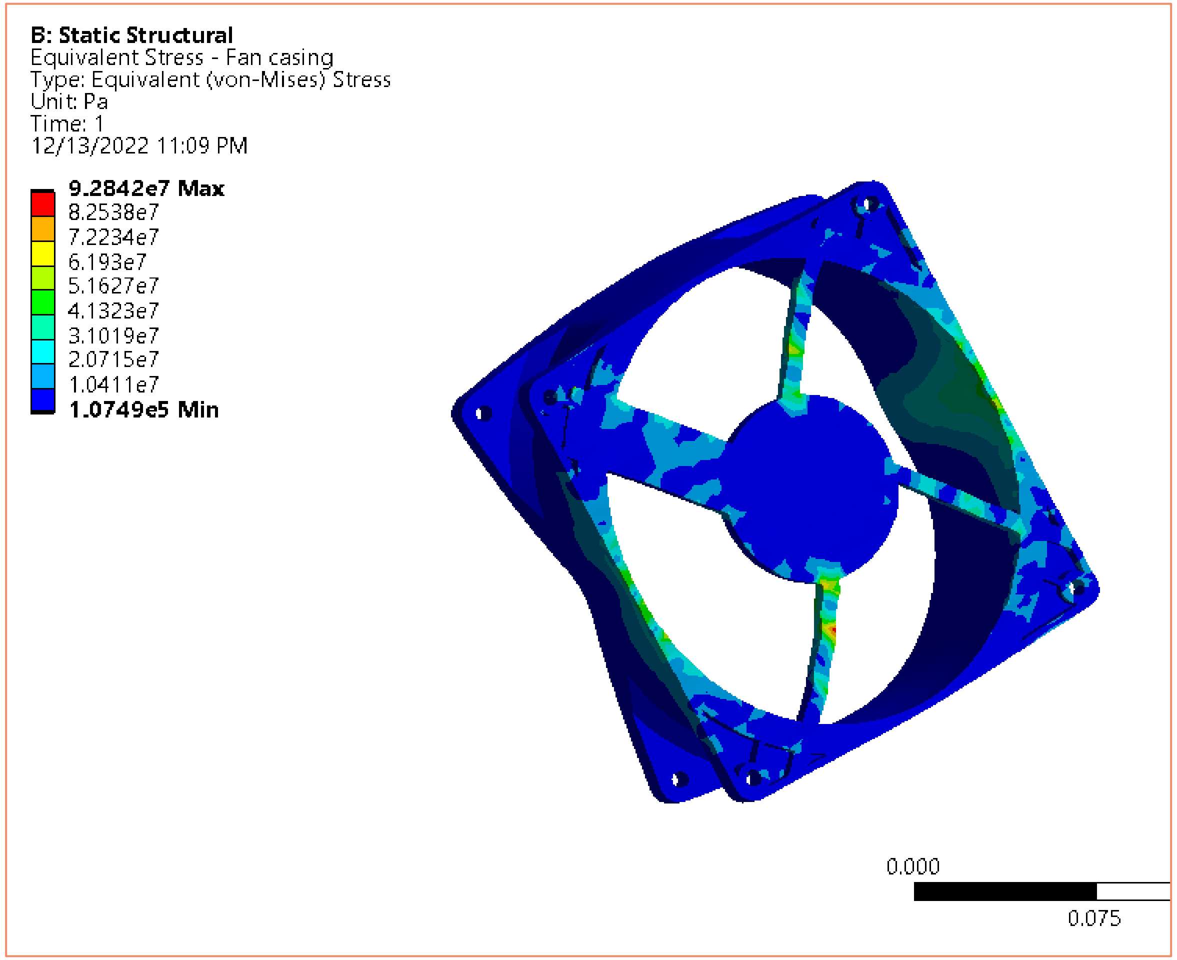


Fig Q: Equivalent stress (von-mises) of fan casing

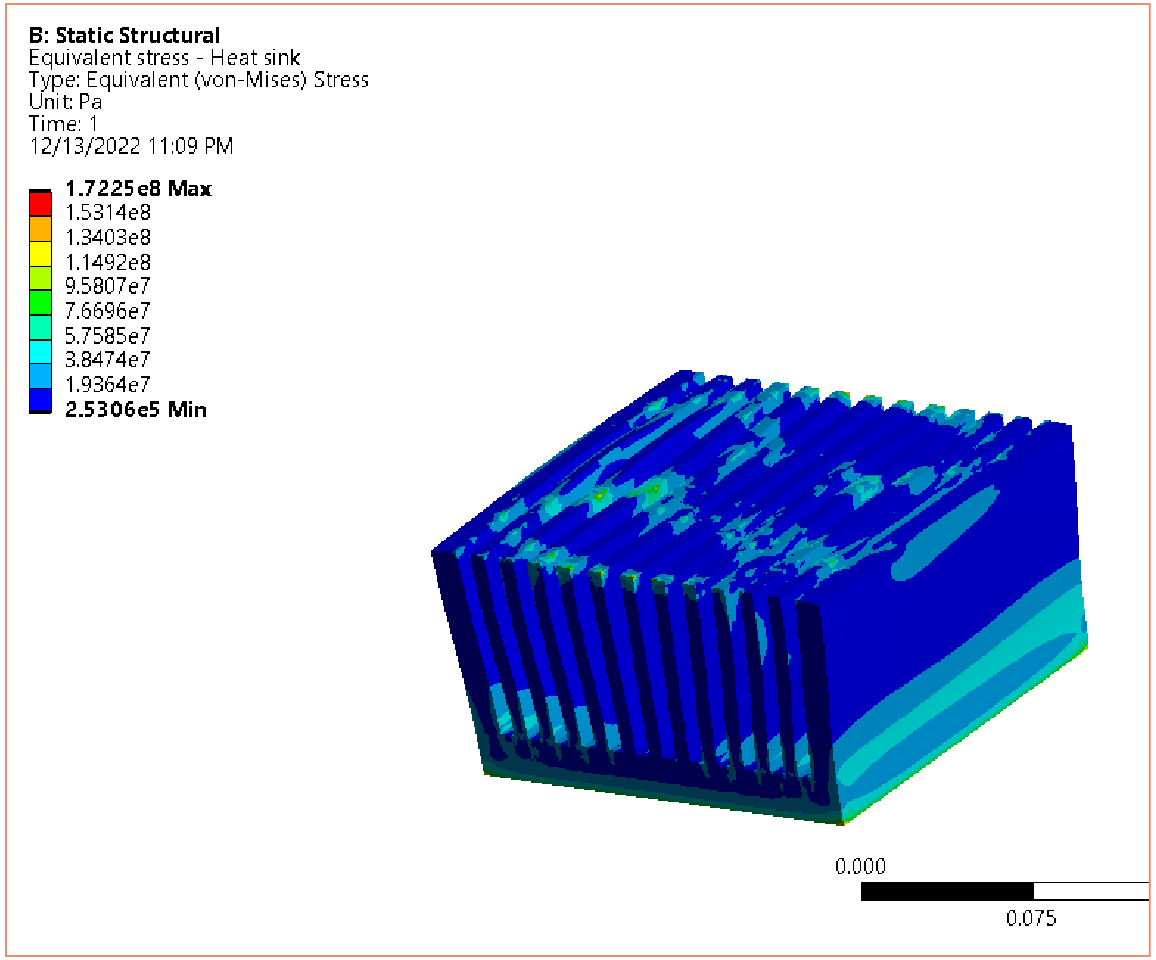


Fig R: Equivalent stress (von-mises) of heat sink

CONTOUR PLOT – TOTAL DEFORMATION OF WHOLE SYSTEM & FAN CASING:

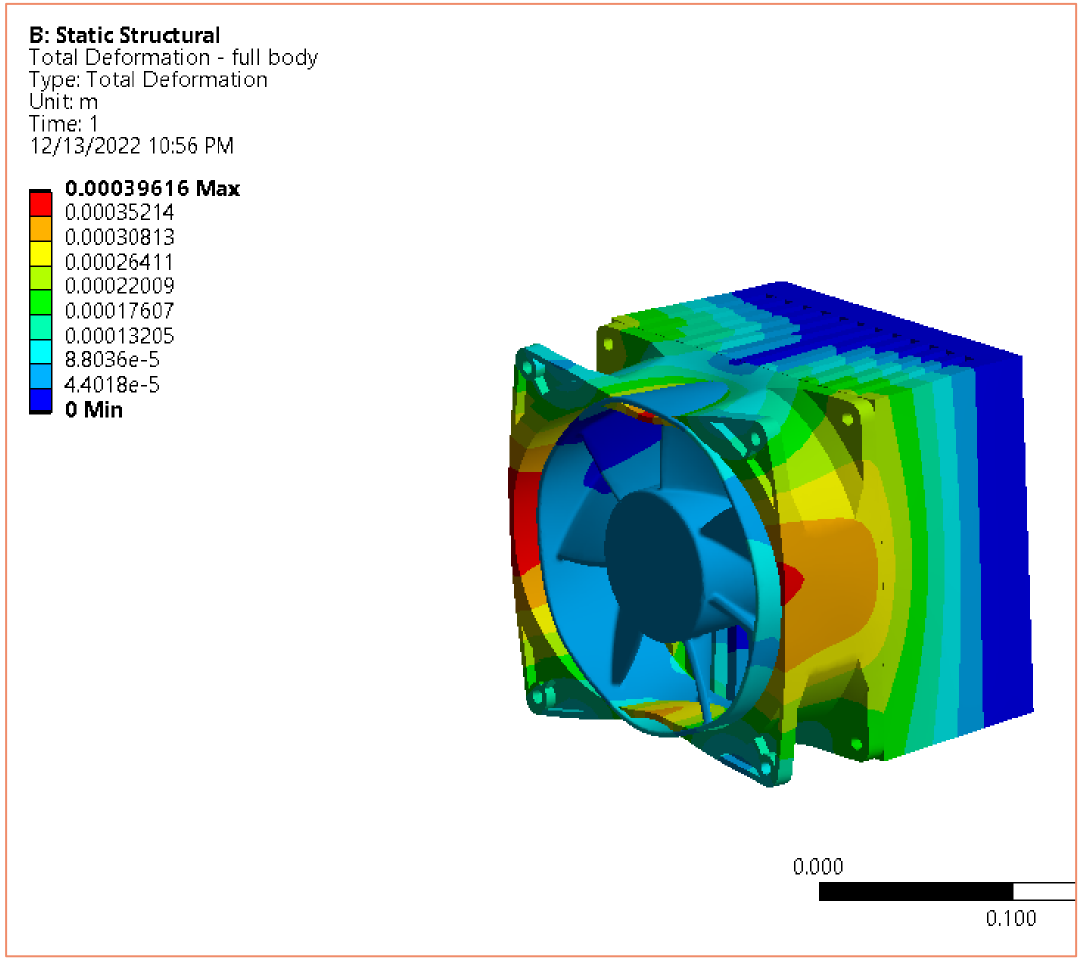


Fig S: Total deformation of whole system

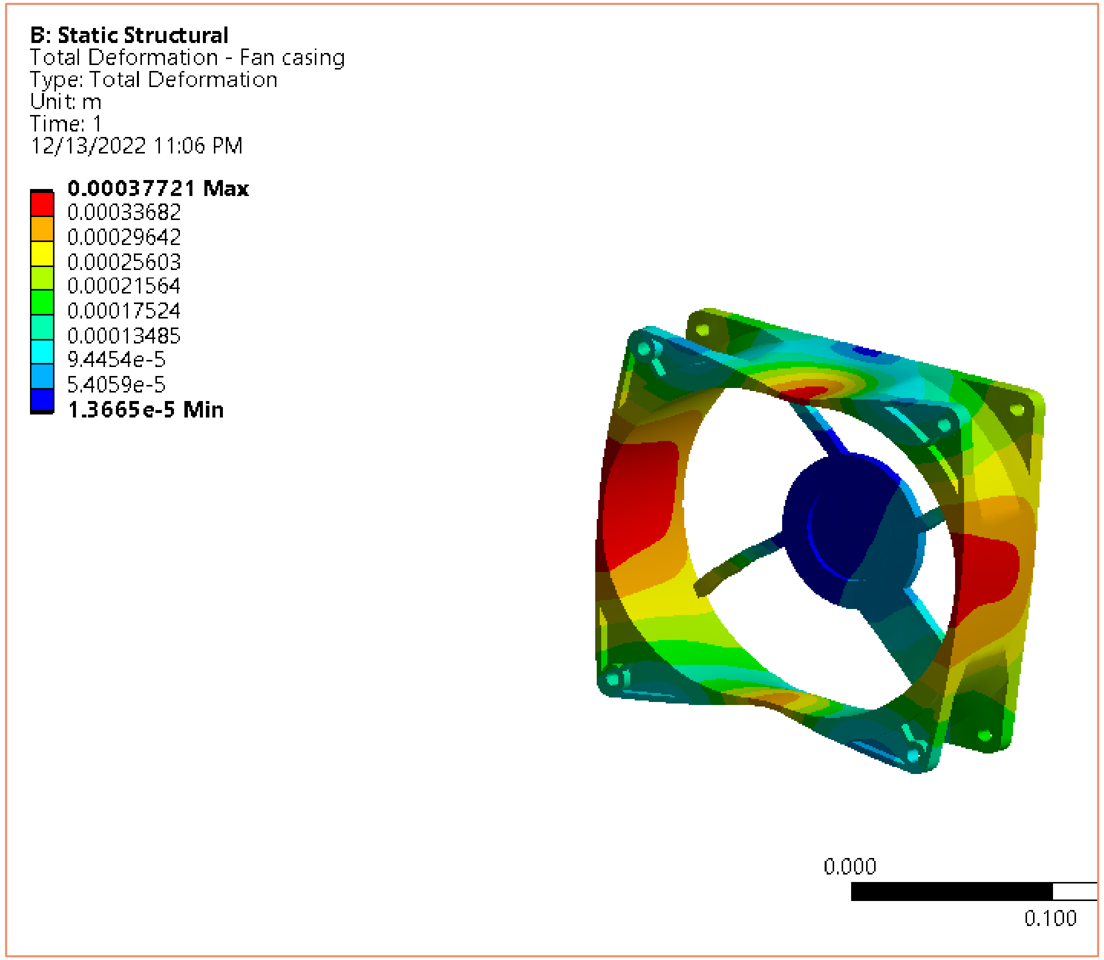


Fig U: Total deformation of fan casing

CONTOUR PLOT – TOTAL DEFORMATION OF FAN & HEAT SINK:

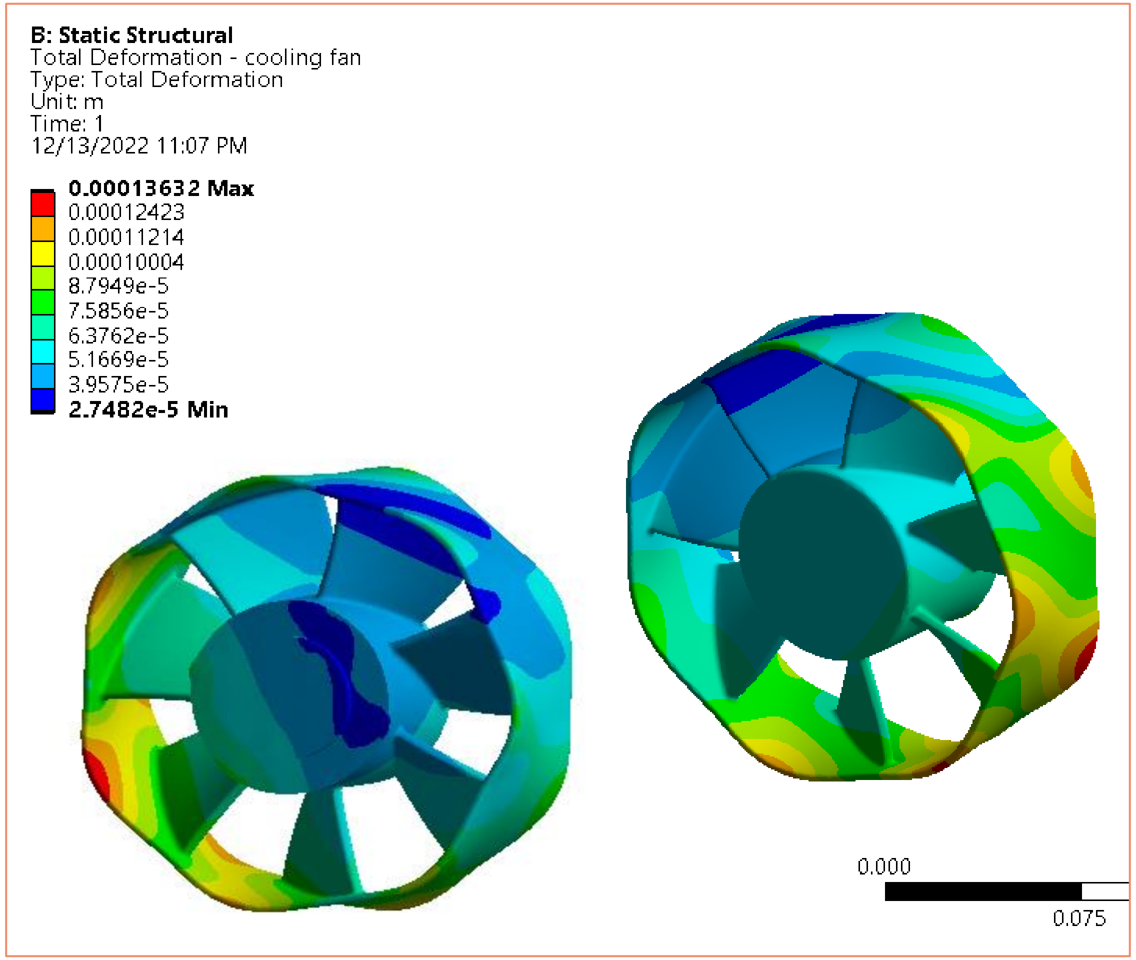


Fig T: Total deformation of fan front & back

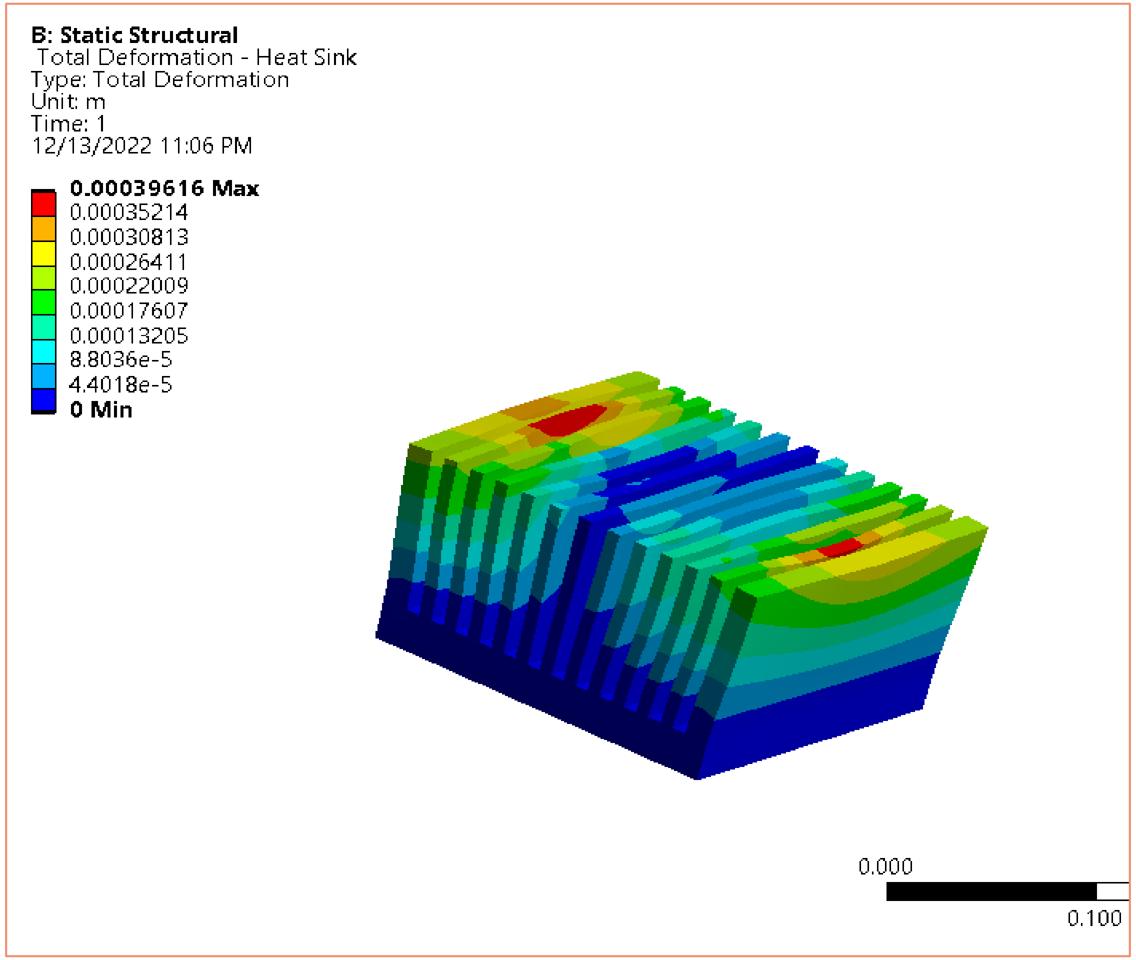


Fig V: Total deformation of heat sink

SAFETY FACTOR – FAN & CASING:

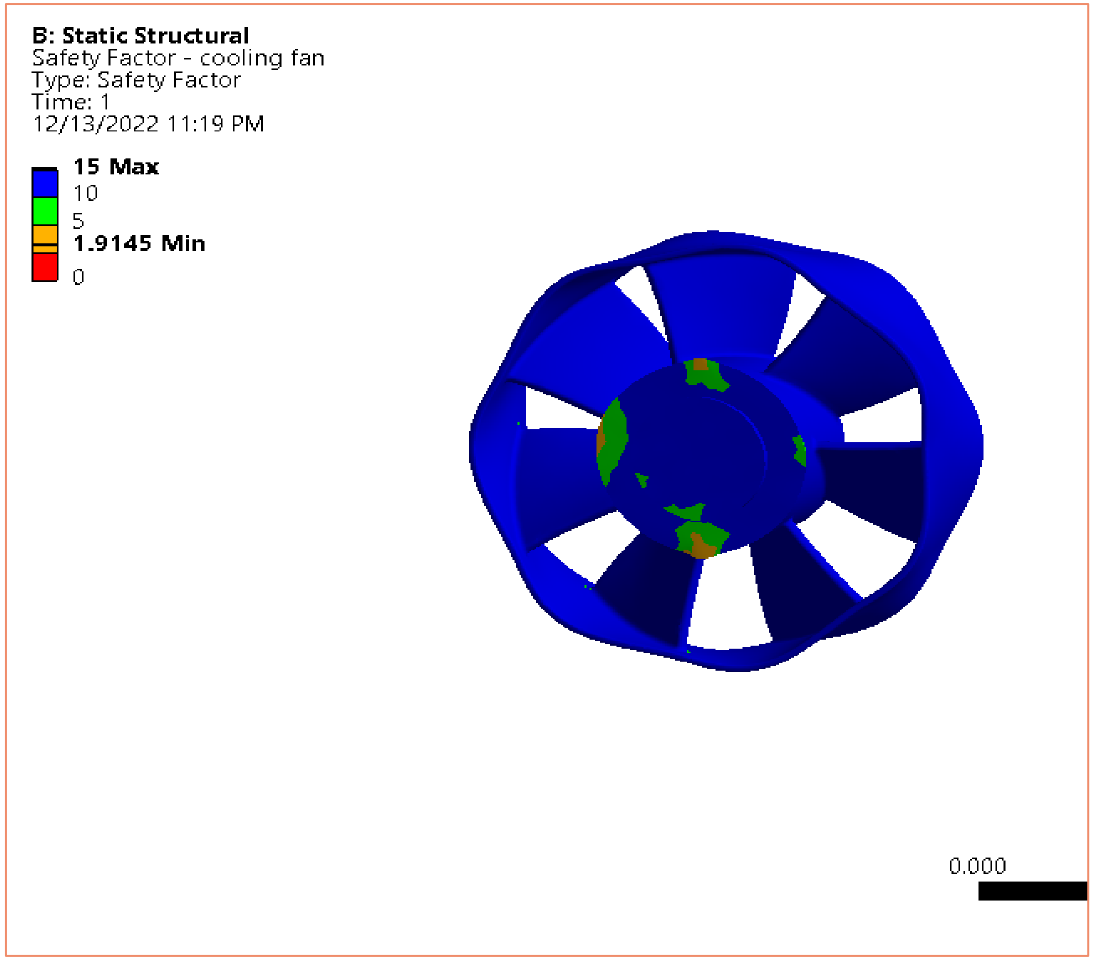


Fig W: Safety factor – cooling fan

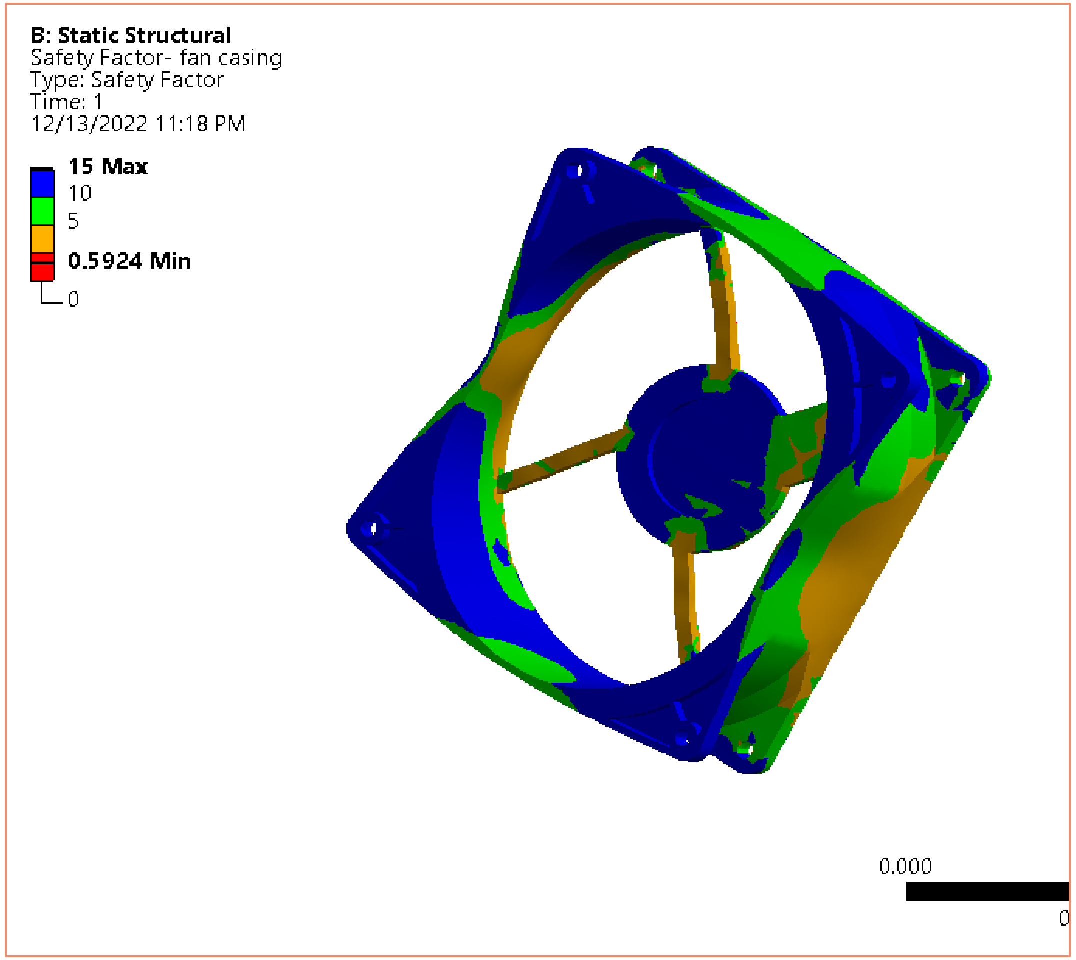


Fig X: Safety Factor - casing

SAFETY FACTOR - HEAT SINK: & CONTOUR PLOT – RADIAL DEFORMATION OF FAN:

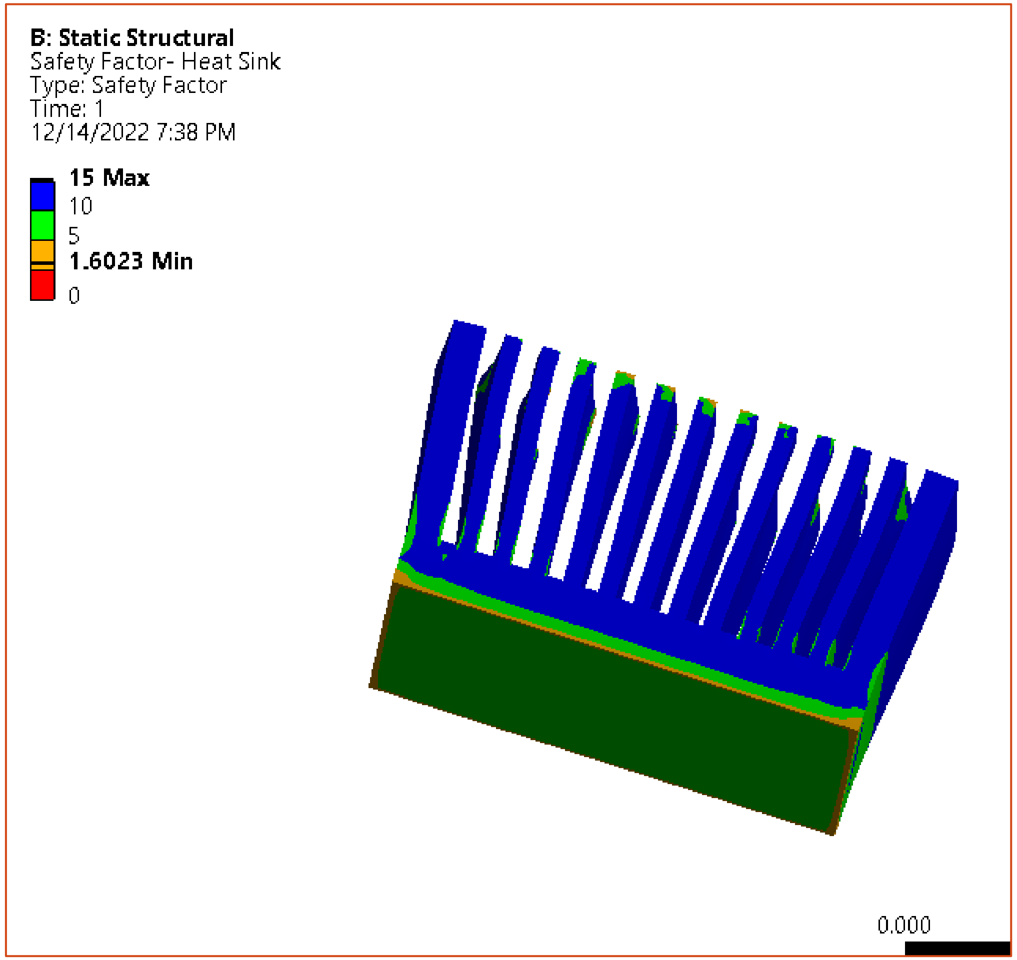


Fig Y: Safety factor – Heat sink

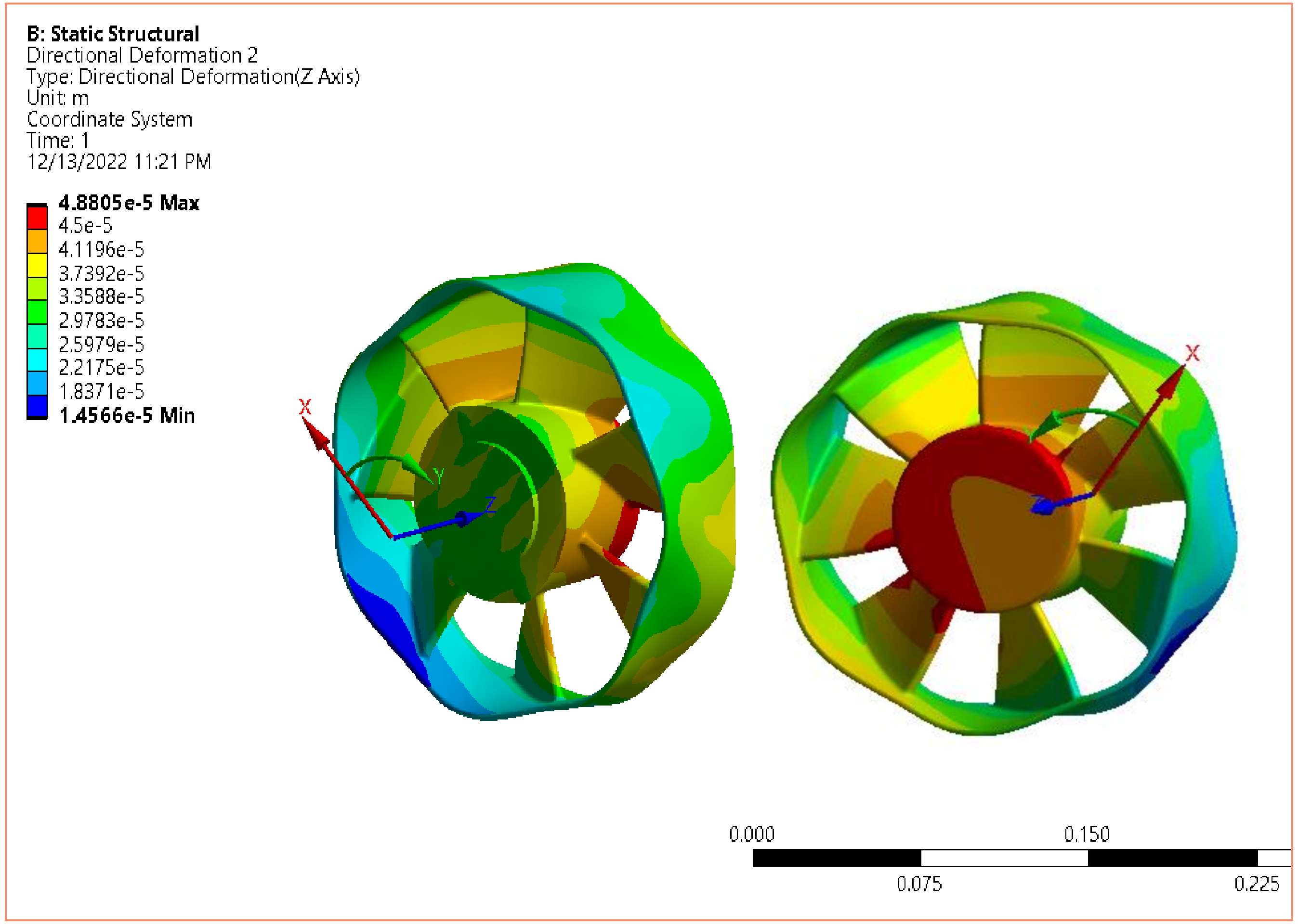


Fig Z: Radial Deformation front and back

RADIAL DEFORMATION OF FAN AND ITS DISCUSSION:

Is the radial deformation (the growth in the diameter of the fan due to loads) is large enough to close the gap between the fan-tip and the casing, and cause the fan tip to hit the casing?

- The magnitude of the radial deformation is said to be 4.8805e-5 max which is equal to 0.048805 mm from the previous image (Fig. Z)
- Where we can find the red region near the center and the slight edges of the fan, where it is not that much large.
- Essentially, it won't affect the velocity and direction of a fluid passing through the fan tip and casing.
- Furthermore, it is safe that the radial deformation would not cause any damage to the tip as well the center region of the fan to hit the casing.

PART 2: STRUCTURAL ANALYSIS OF THE FAN COMPONENT ONLY

GEOMETRY OF ENTIRE FAN SYSTEM:

Fig. A: Geometry

MODEL MESH FOR FULL MODEL:

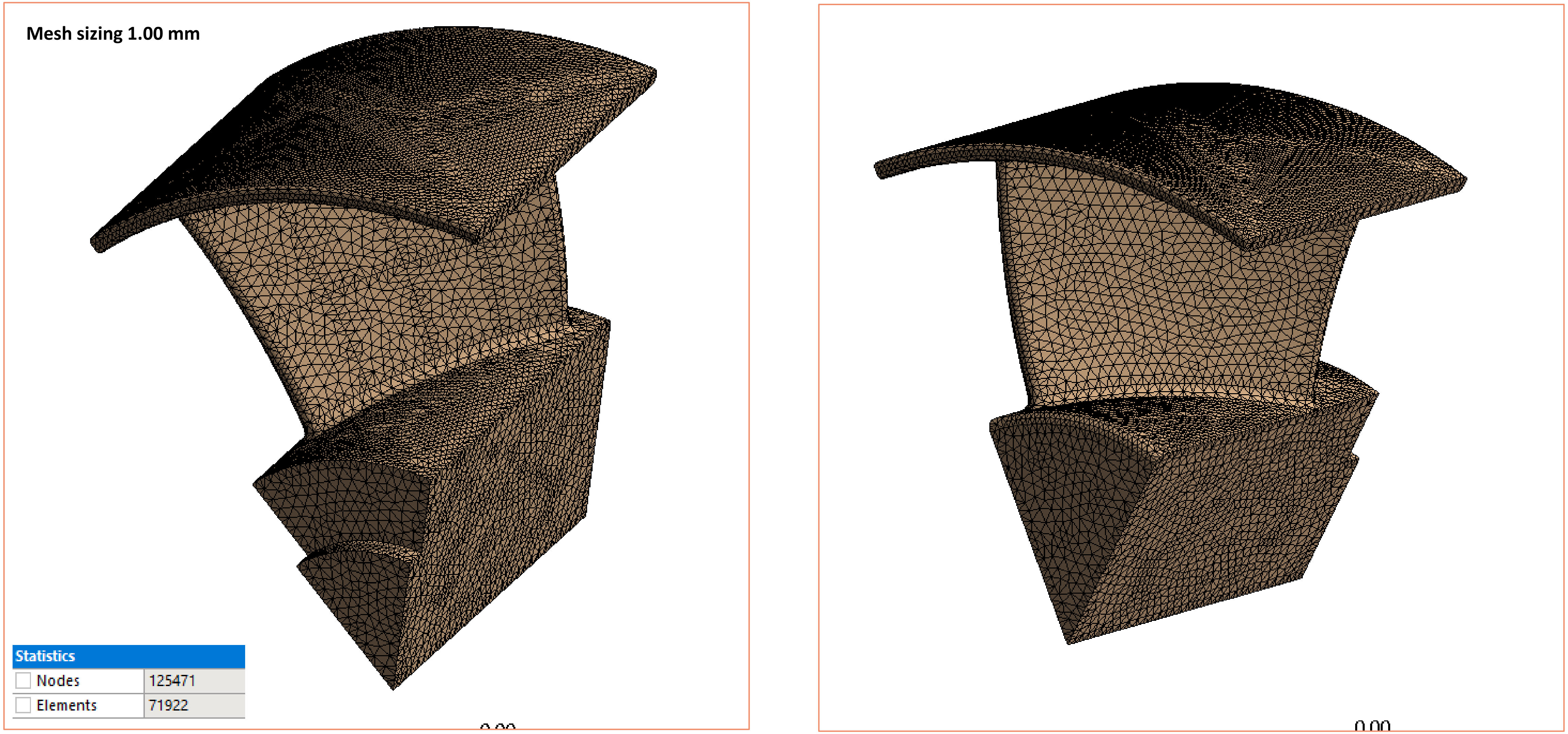
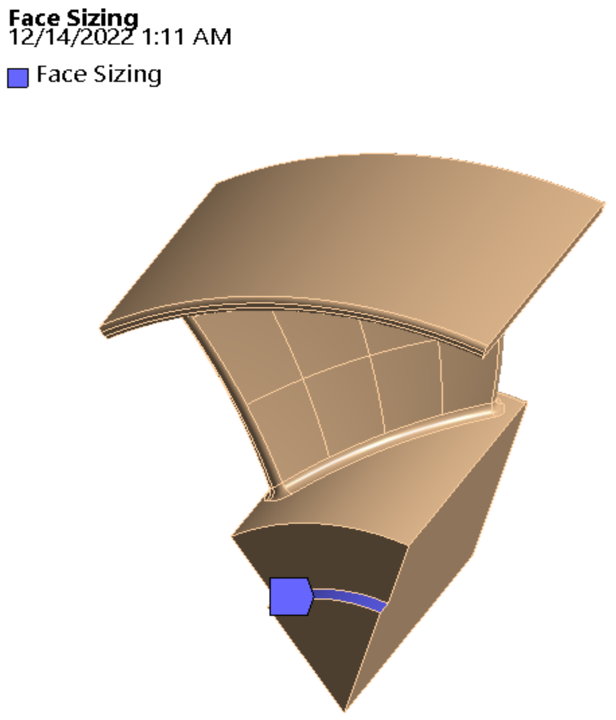


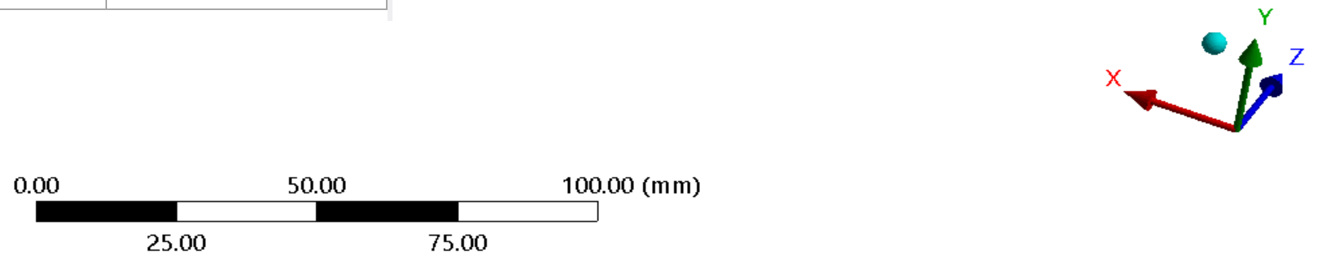
Fig. B: Mesh of the body

MODEL MESH FOR FULL MODEL:



Details of "Face Sizing" - Sizing

Scope	
Scoping Method	Geometry Selection
Geometry	1 Face
Definition	
Suppressed	No
Type	Element Size
Element Size	1.0 mm
Advanced	
Defeature Size	Default
Influence Volume	No
Behavior	Soft



Implementing the face sizing due to its geometry complexity, as it uses only 1/7th of the sector, so smaller cell size is required to create a fine mesh.

Fig. C Face mesh

BOUNDARY CONDITIONS FOR STRUCTURAL ANALYSIS – CYCLIC REGION:

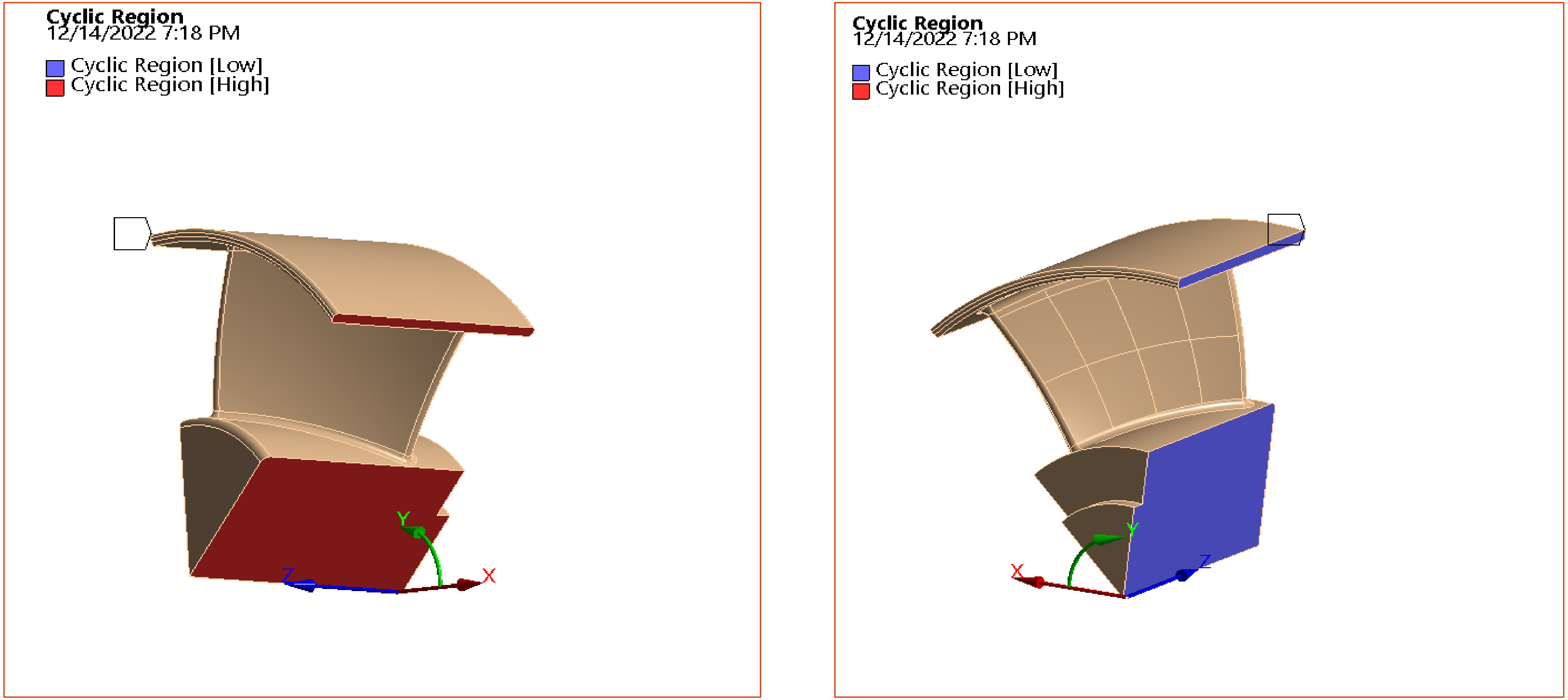
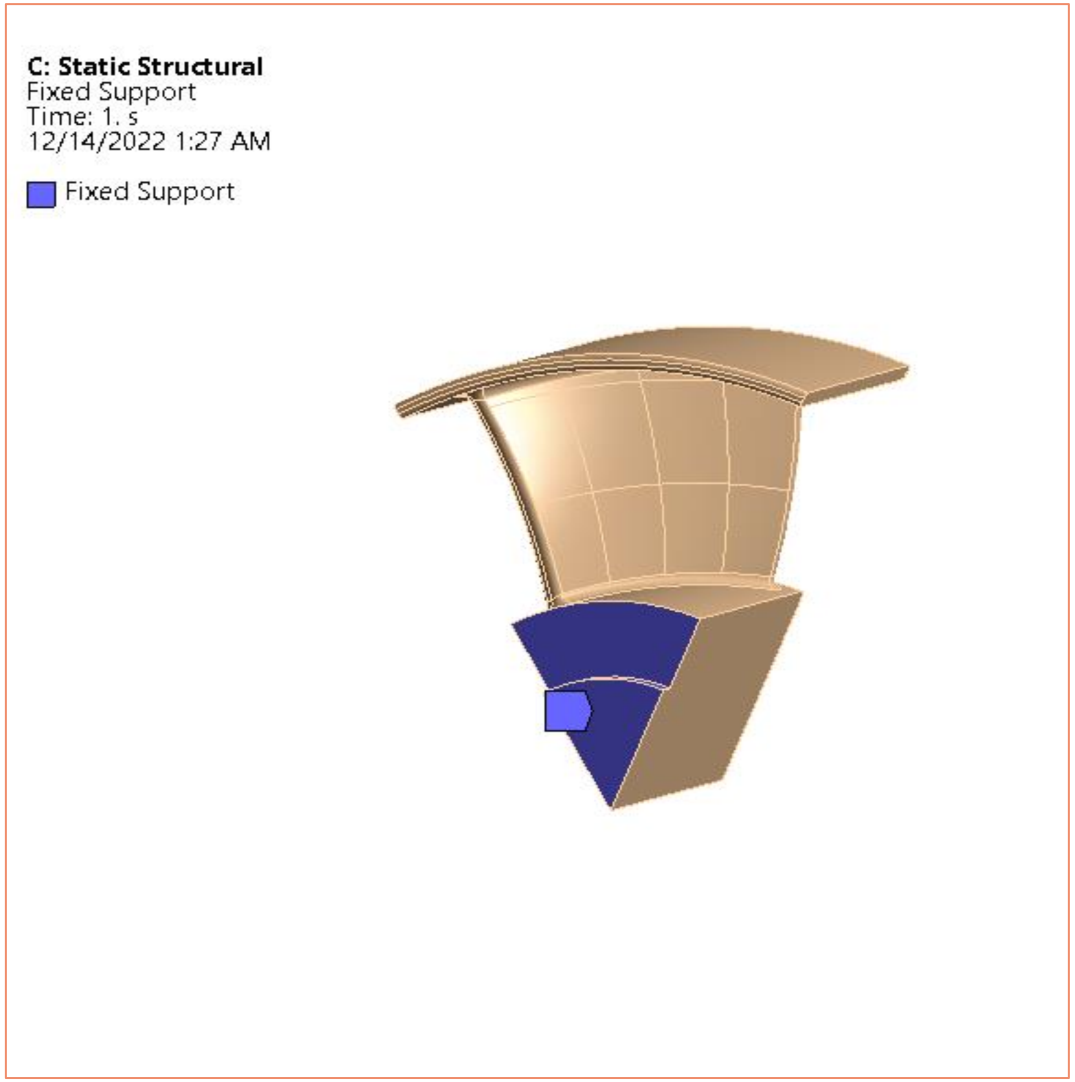
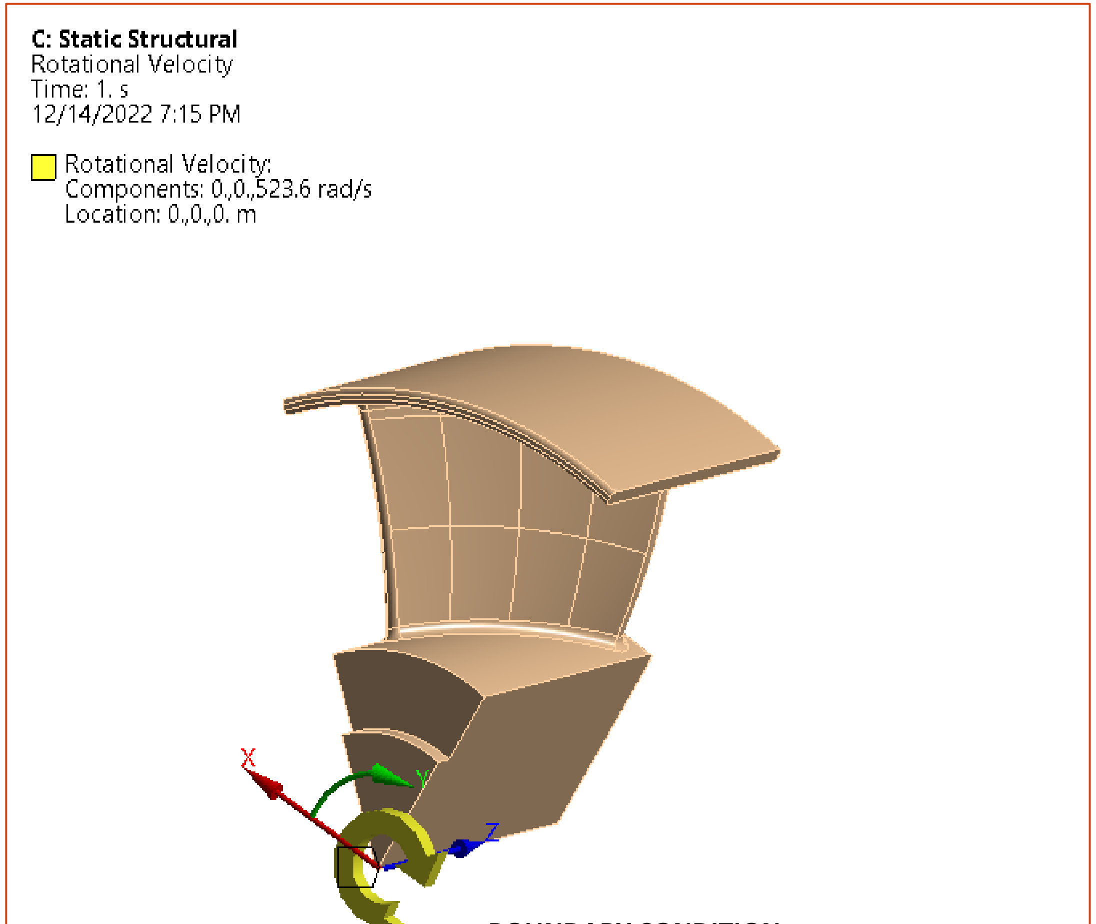


Fig. D: Boundary conditions

BOUNDARY CONDITIONS - FOR STRUCTURAL ANALYSIS FIXED AND ROTATIONAL VELOCITY:



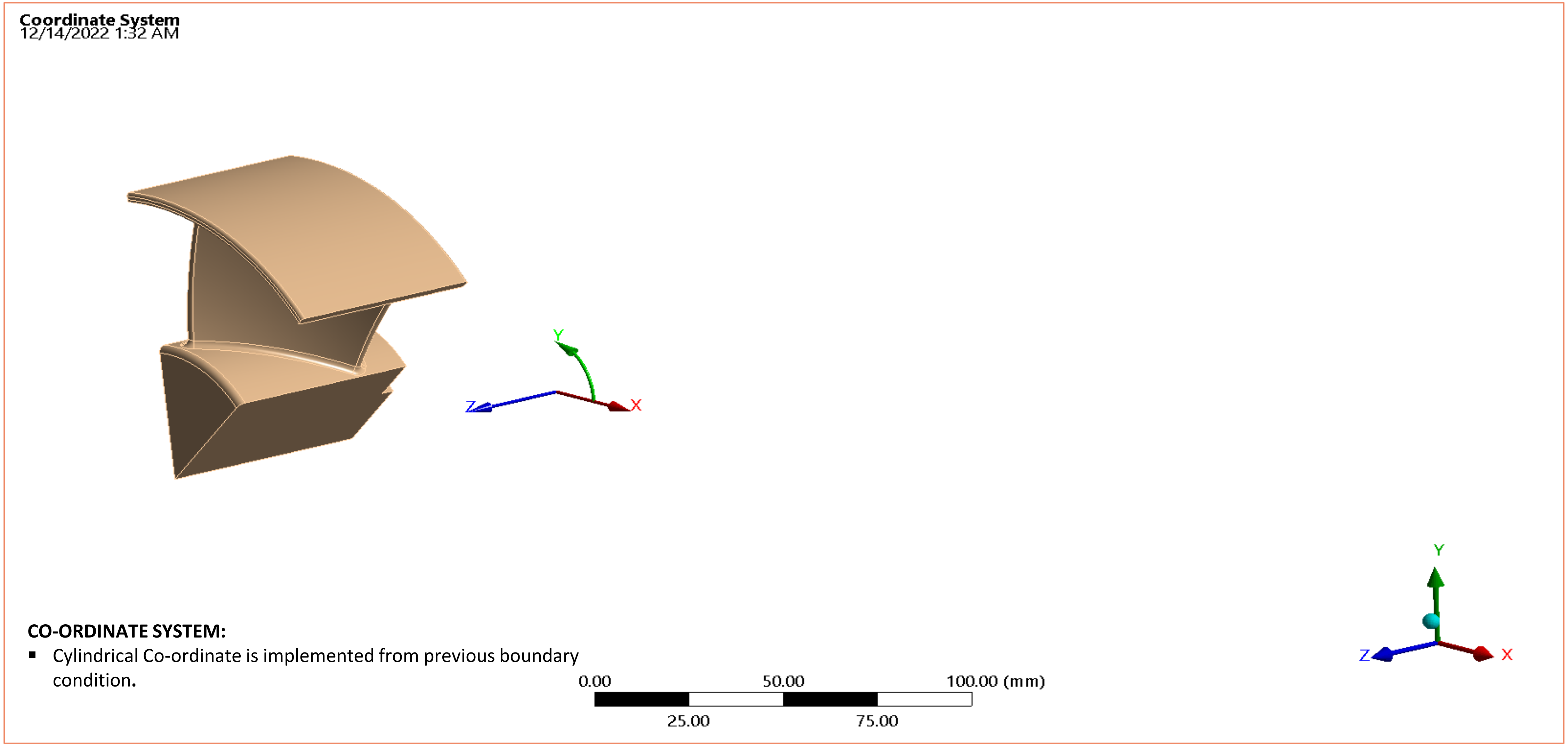


BOUNDARY CONDITION:

- Rotation velocity acting at 5000 RPM.

Fig. E: Boundary conditions

CO-ORDINATE SYSTEM:



CO-ORDINATE SYSTEM:

- Cylindrical Co-ordinate is implemented from previous boundary condition.

Fig. F: Co Ordinate System

COUNTOUR PLOT OF TOTAL DEFORMATION OF FAN:

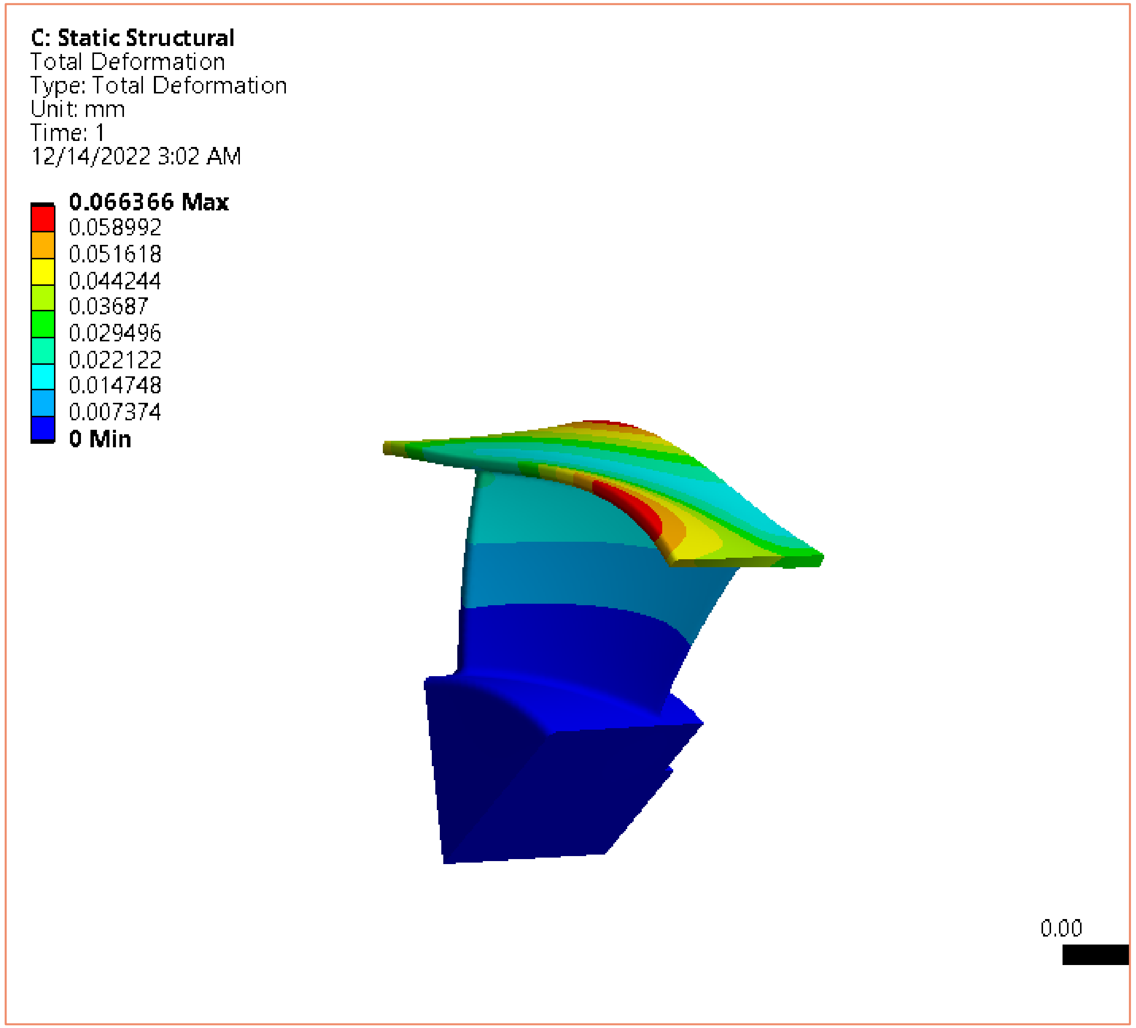


Fig. G: contour plots

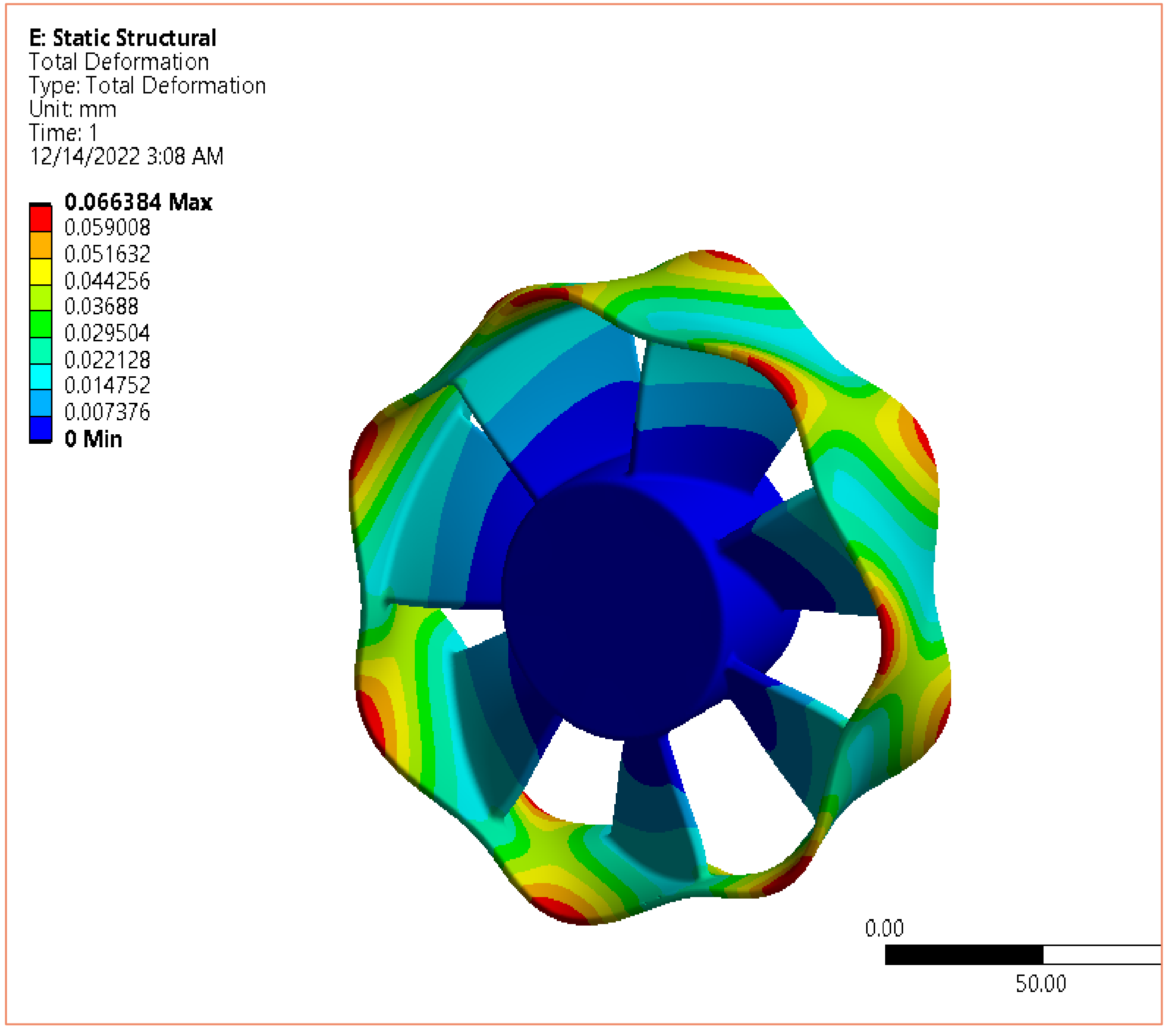


Fig. G1: Contour plots

CONTOUR PLOT OF RADIAL DEFORMATION OF FAN:

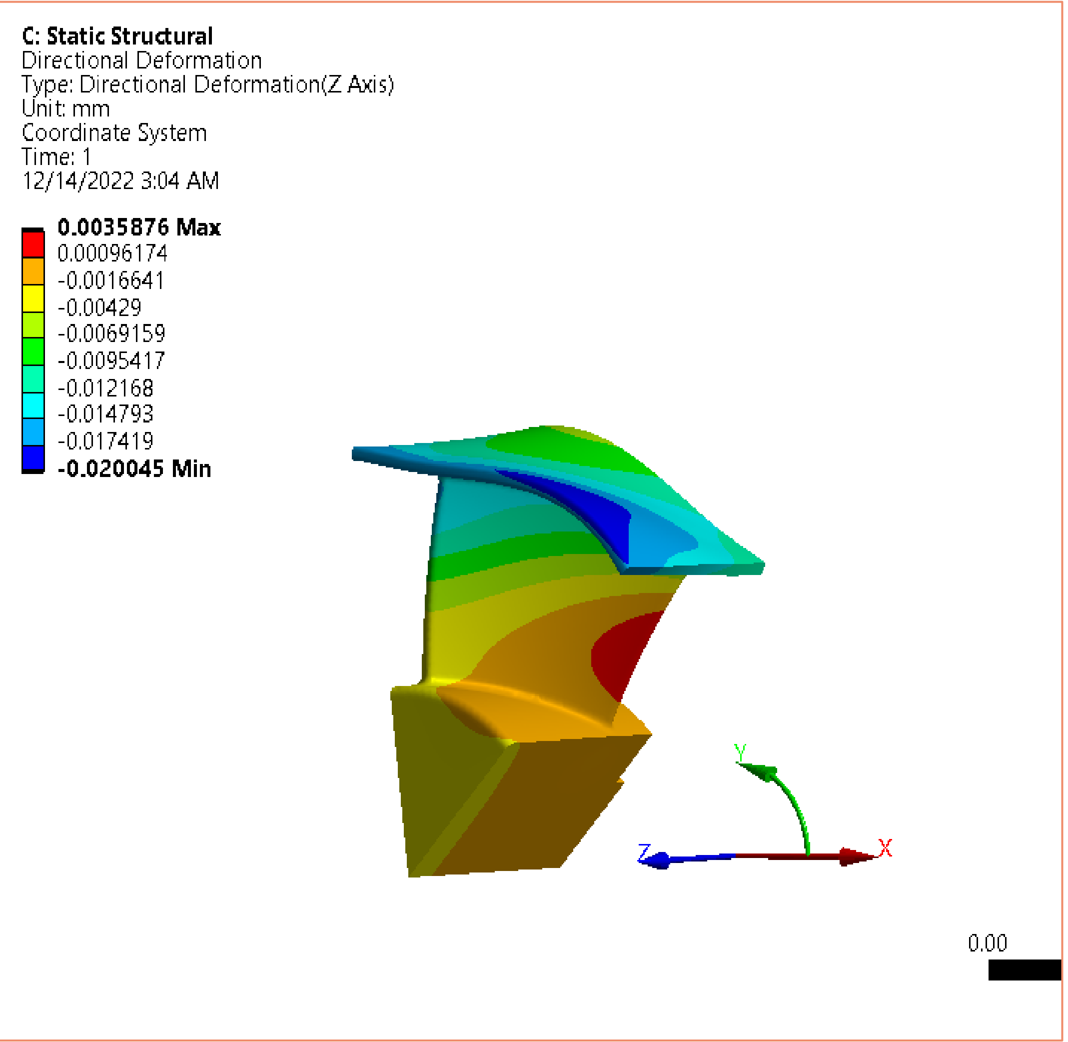


Fig. H: Contour plot

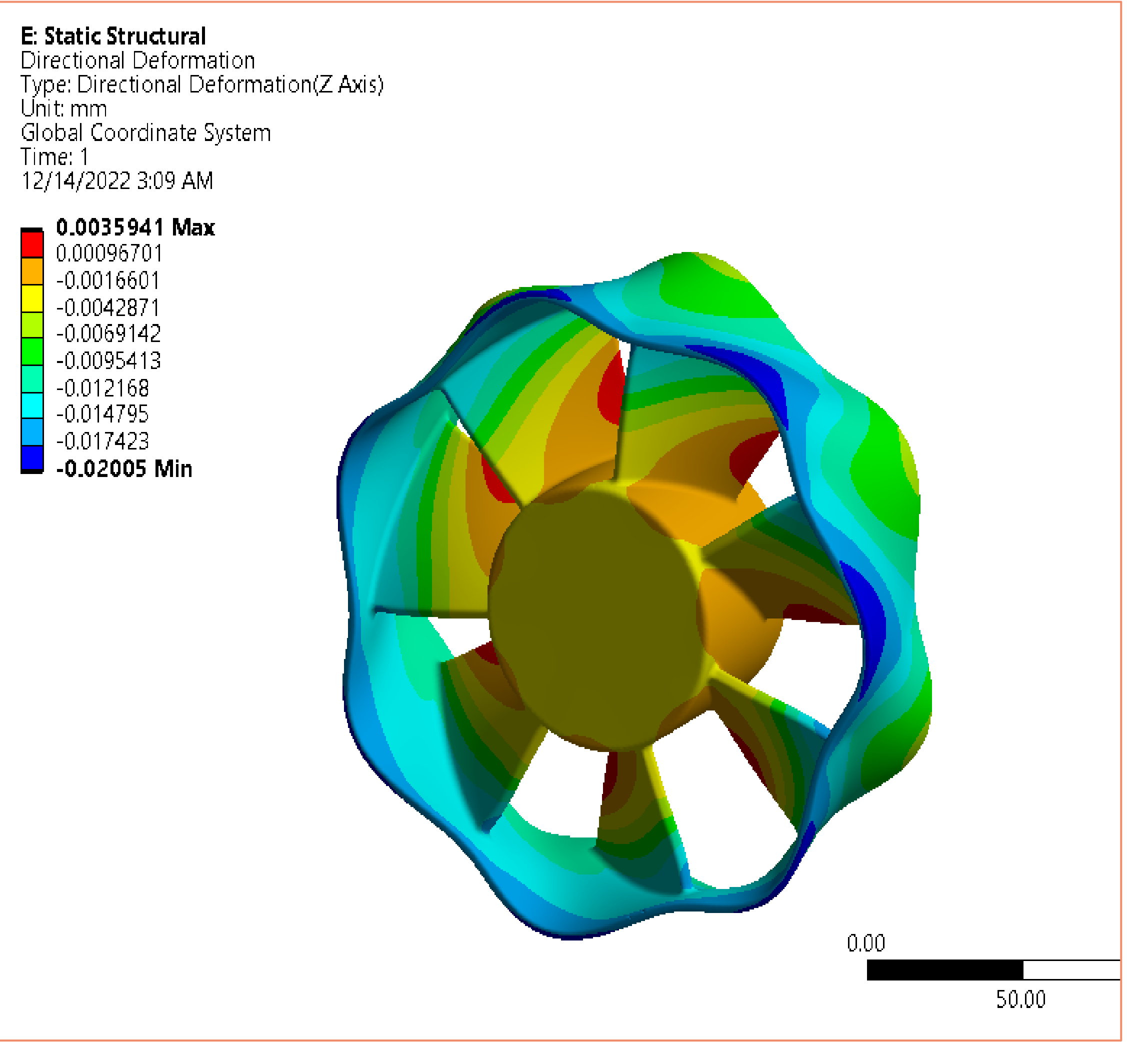


Fig. H1: Contour plot

CONTOUR PLOT OF STRESS OF FAN:

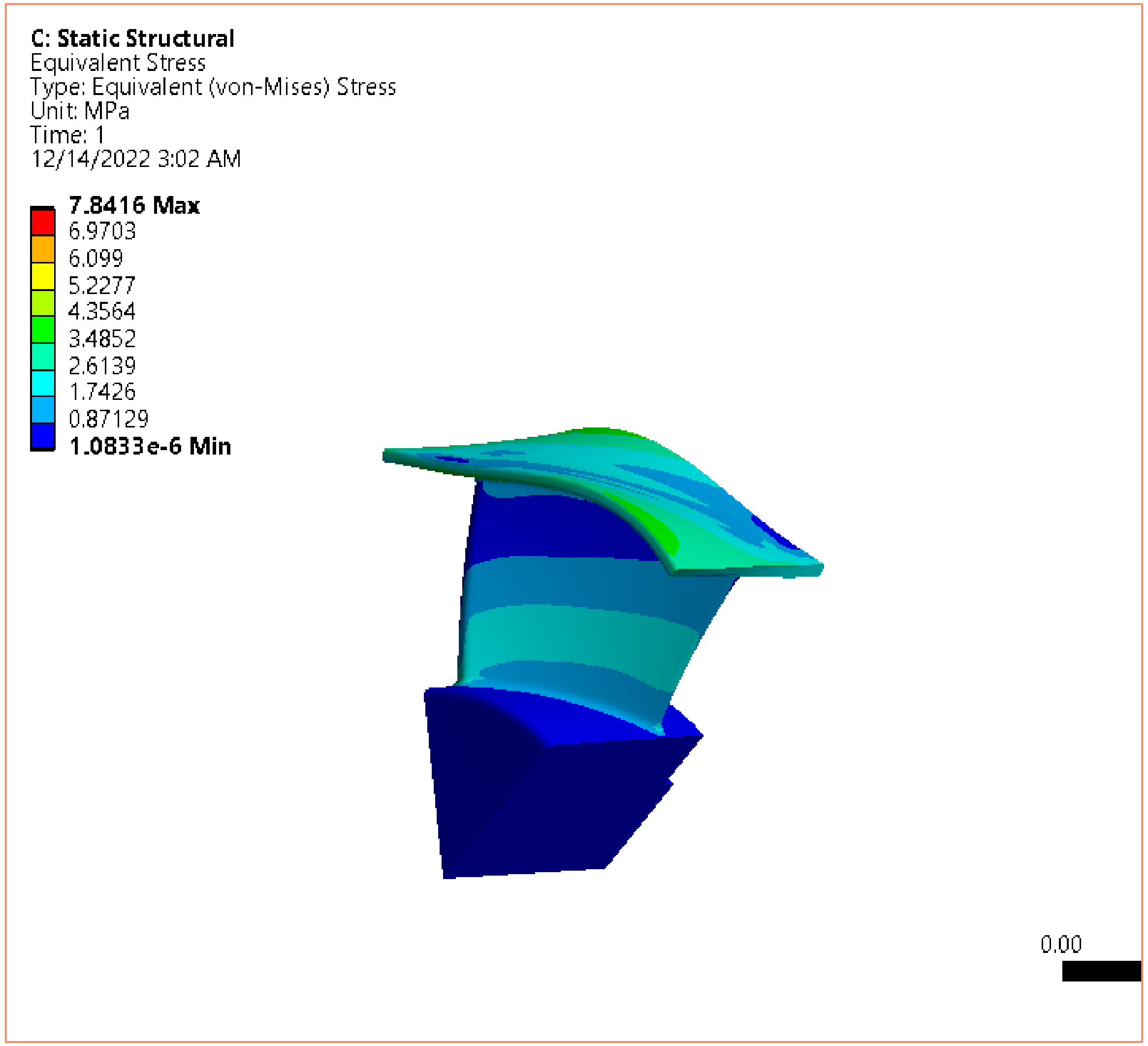


Fig. I Contour plot

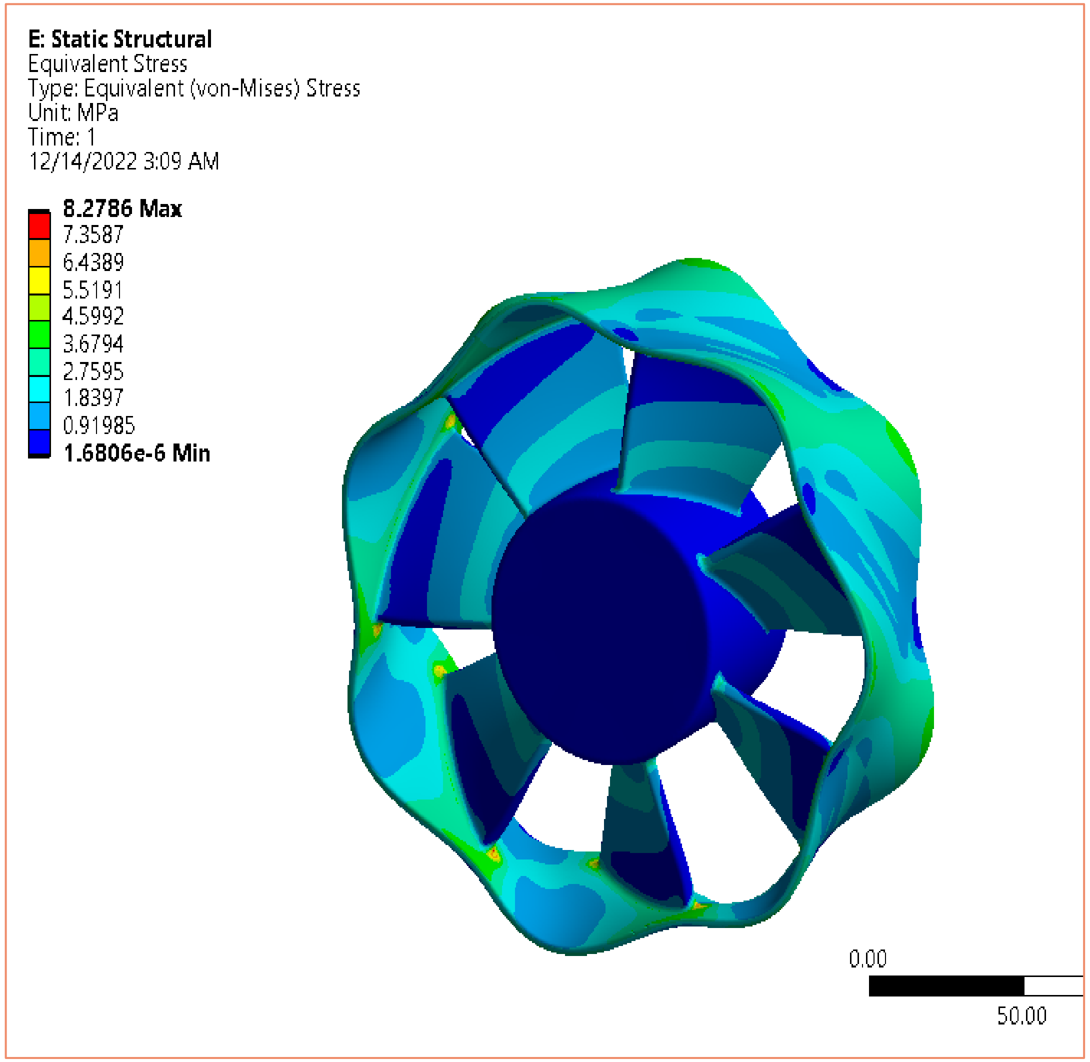


Fig. I 1 Contour plot

SAFETY FACTOR OF FAN:

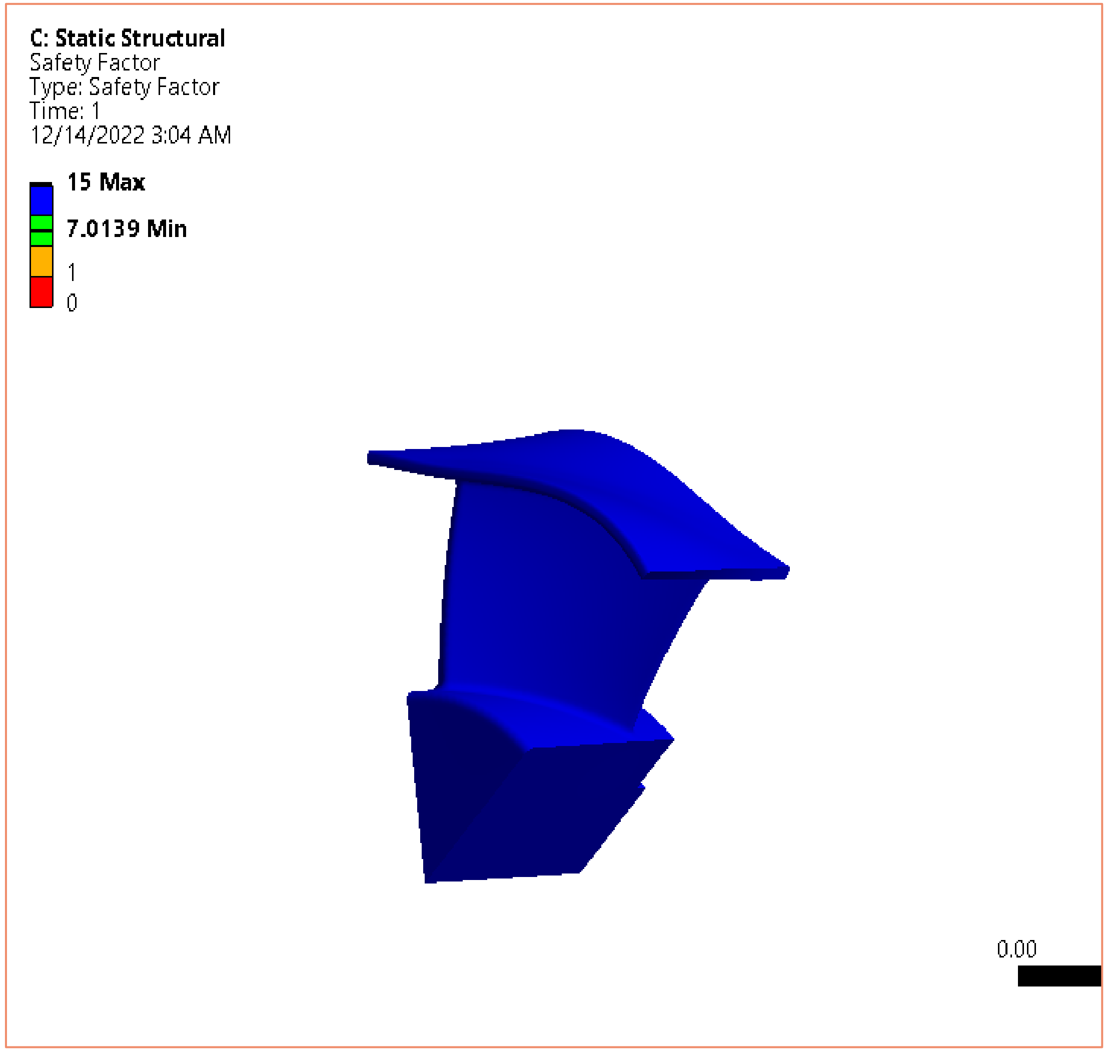


Fig. K: safety factor

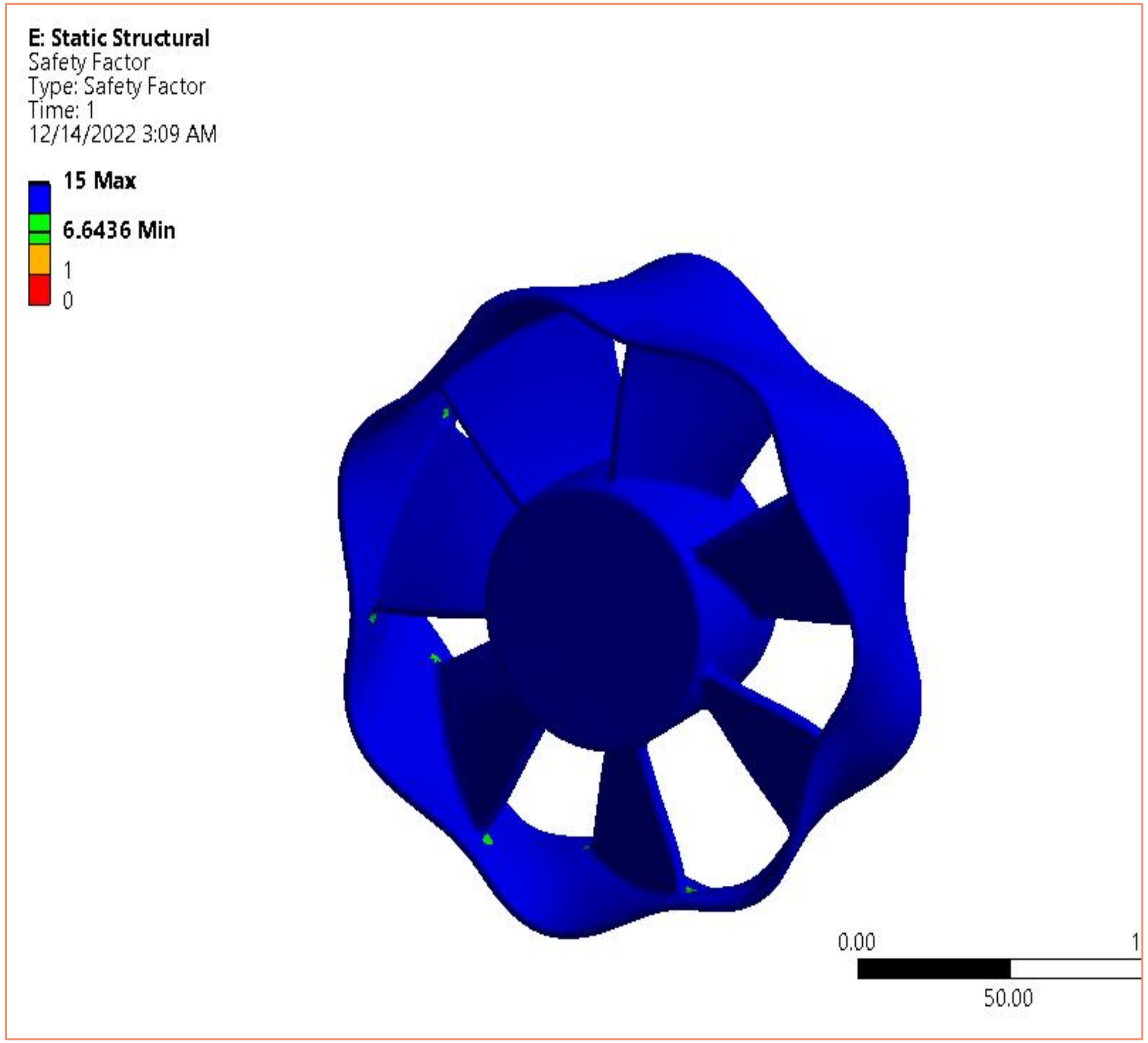


Fig. K1: safety factor

COMPARISION OF RESULTS TO PART 1:

- When we go through the stress and the total deformation in part 2, it is more than the stress which is in part 1.
- Its because of the temperature load in part 1, which is not present in part 2.
- If you see the safety factor it changes, but in some time, it remains constant.

PARAMETRIC ANALSYSIS OF A FAN:

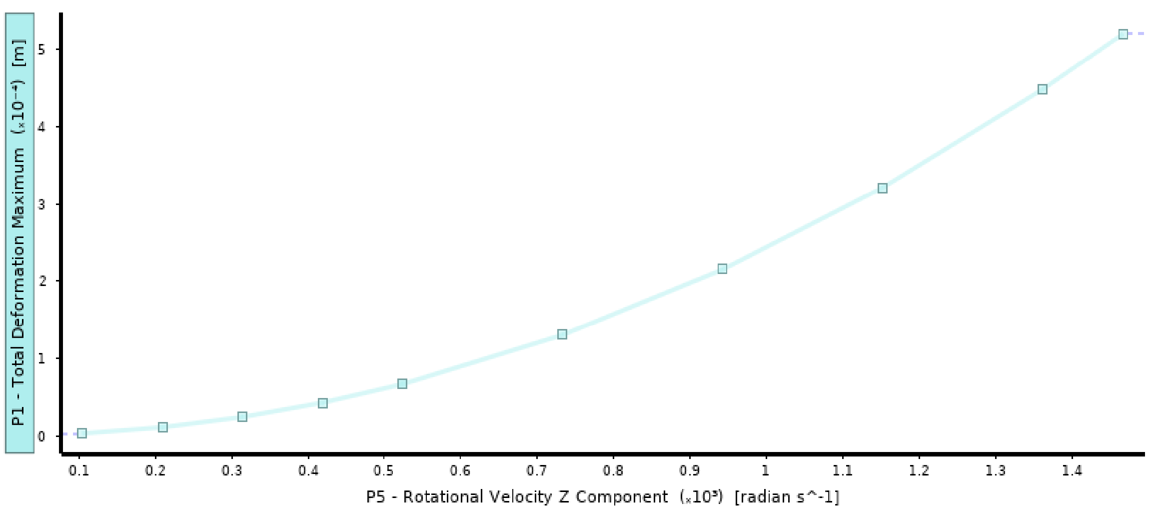


Fig. Graph 1: X- axis: Rotational velocity: Y-Axis: Total deformation

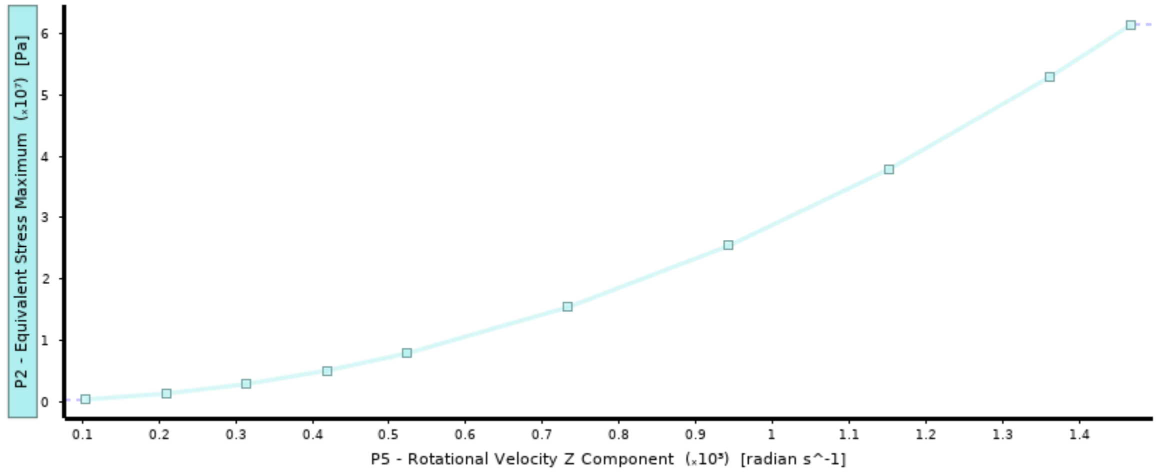


Fig. Graph 2: X- axis: Rotational velocity: Y-Axis: Equivalent stress maximum.

- For this parametric analysis set, the rotational velocity is kept as the input parameter as per the given question. I have performed 11 simulations using the rotational velocity values starting from 0 to 15000 RPM. Where I have kept 1000 RPM as an interval from 1000 – 5000 RPM and 2000 RPM as an interval element from 5000 – 13000 RPM.

- The above fig shows the relationship between the two output parameters and the rotational velocity is exponential growth.

- Where we know that, fundamental structural mechanics and linear elastic theory shows an increase in rotational velocity, where the deformation and stress of a body will get increased.

PARAMETRIC ANALSYSIS OF A FAN:

ROTATIONAL VELOCITY (RPM)	SAFETY FACTOR
0	0
1000	15
2000	15
3000	15
4000	10.95917911
5000	7.013874541
7000	3.578504356
9000	2.164776082
11000	1.449147643
13000	1.037555405
15000	0.894626855

Fig. Table 1: Safety Factor

Table of Design Points

	A	B	C	D	E	F
1	Name	P5 - Rotational Velocity Z Component	P1 - Total Deformation Maximum	P2 - Equivalent Stress Maximum	P3 - Directional Deformation Maximum	P4 - Safety Factor Minimum
2	Units	radian s^-1	m	Pa	m	
3	DP 0 (Current)	523.6	6.6366E-05	7.8663E+06	3.5868E-06	6.9918
4	DP 1	104.72	2.6546E-06	3.1366E+05	1.435E-07	15
5	DP 2	209.44	1.0619E-05	1.2547E+06	5.7402E-07	15
6	DP 3	314.16	2.3892E-05	2.823E+06	1.2915E-06	15
7	DP 4	418.88	4.2474E-05	5.0186E+06	2.2961E-06	10.959
8	DP 5	523.6	6.6366E-05	7.8416E+06	3.5876E-06	7.0139
9	DP 6	733.04	0.00013008	1.537E+07	7.0317E-06	3.5785
10	DP 7	942.48	0.00021503	2.5407E+07	1.1624E-05	2.1648
11	DP 8	1151.9	0.00032121	3.7953E+07	1.7364E-05	1.4491
12	DP 9	1361.4	0.00044863	5.3009E+07	2.4252E-05	1.0376
13	DP 10	1466.1	0.00052031	6.1478E+07	2.8127E-05	0.89463
*						

Fig. Table 2: parametric chart

- In order to have a safety factor at least 1.5, the maximum rotational velocity of the fan should not exceed 11000 RPM, which can we clearly see that from the above tables.
- When the fan is rotating at 11000 RPM, the equivalent stress (von-mises) has a magnitude of 37.95 MPa and the total deformation is said to be 0.3212 mm.
- When the fan is rotating greater or equal to 5000 RPM, there will be some risk where the casing gets damaged by the fan. For instance, if you spin a fan at 13000 RPM, you can find the total deformation to be greater than 0.3212 mm(11000) rpm, and there is a probability of the fan to hit the casing.

PART 3: MODAL ANALYSIS OF THE FAN COMPONENT ONLY

GEOMETRY, MODAL MESH, AND BOUNDARY CONDITIONS OF FAN BLADE.:

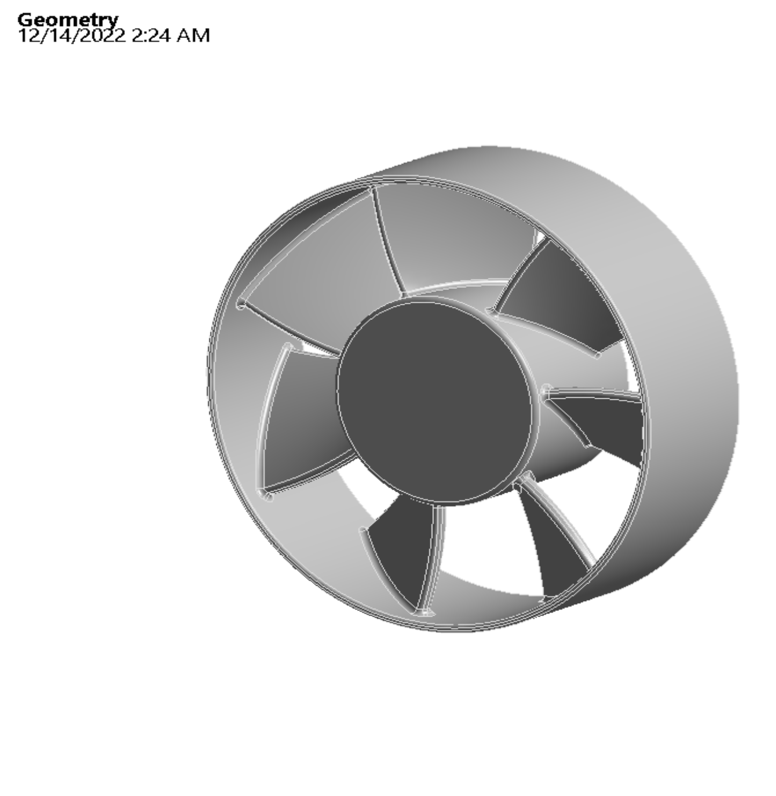


Fig. A: Geometry of fan blade

Statistics	
Nodes	814260
Elements	472525

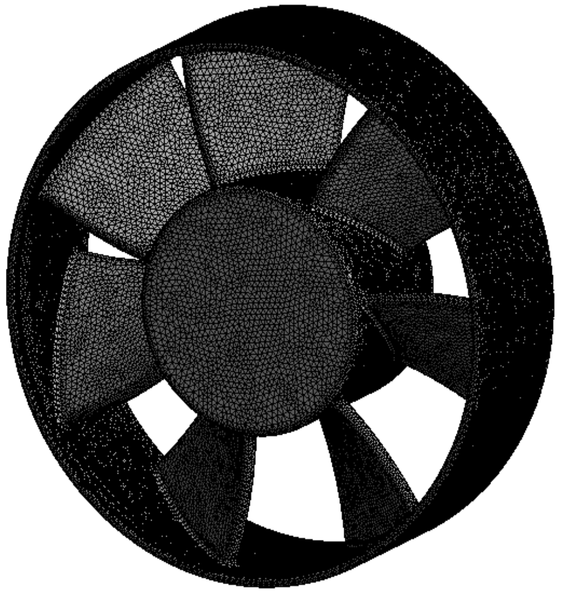
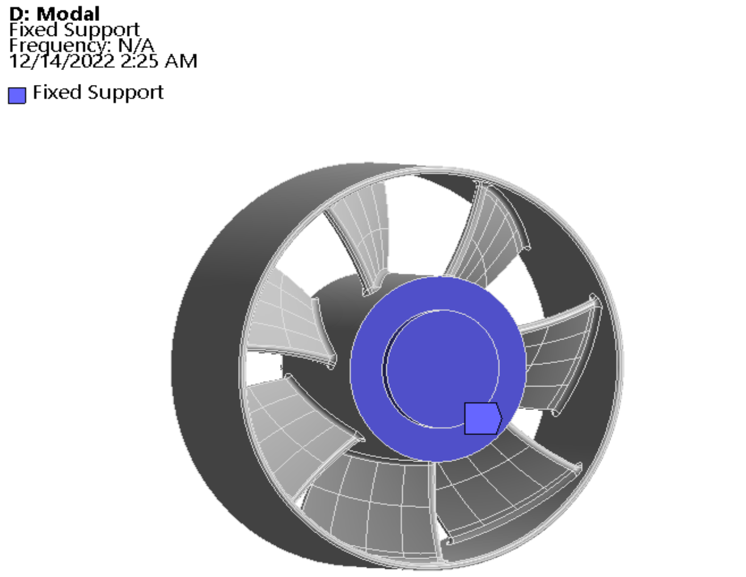


Fig. B: Mesh for the fan blade



BOUNDARY CONDITIONS:

- Back of fan blade is fixed.

0.00

Fig C: Boundary condition for modal analysis

RESULTS FOR FAN-MODAL (1-6) ANALYSIS (GRAPH & TABLE):

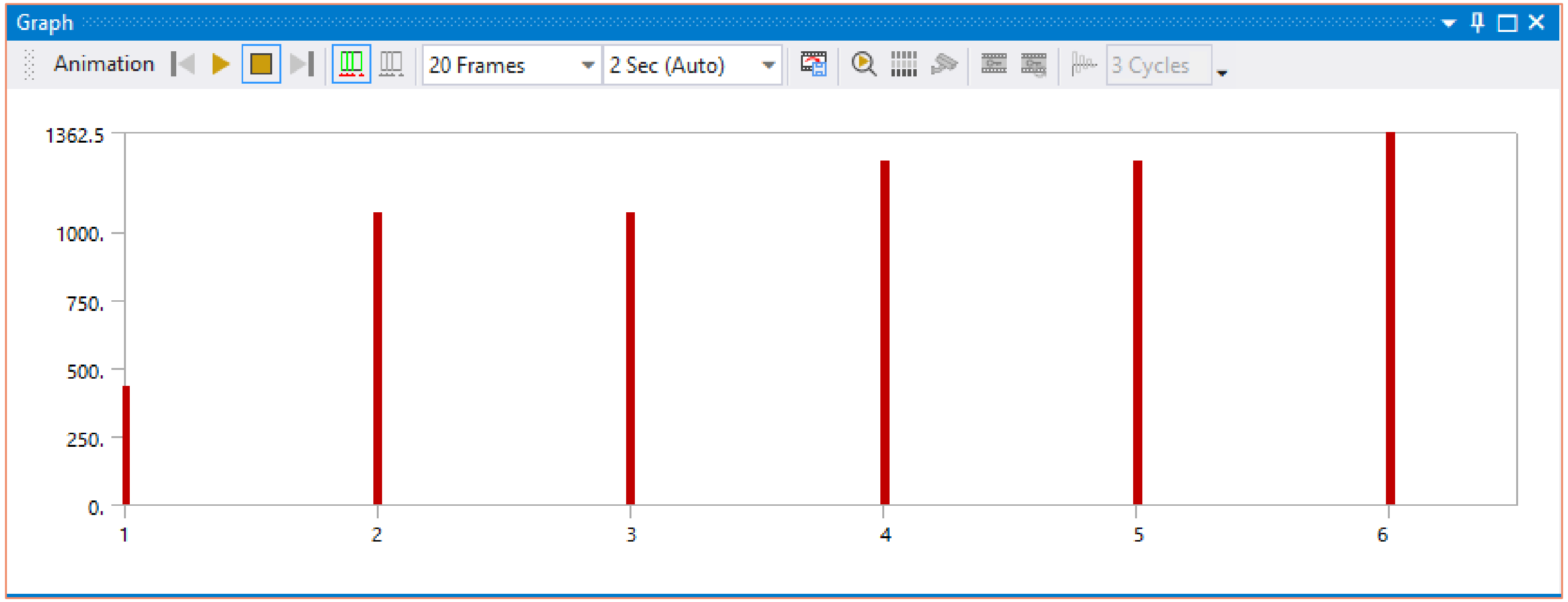


Fig. D: FREQUENCY GRAPH & TABLE

MODE	NATURAL FREQUENCY (Hz)
1	432.35
2	1068
3	1068
4	1260.7
5	1260.7
6	1362.5

TABLE 1: Natural frequency for first 6 nodes.

RESULTS FOR FAN-MODAL ANALYSIS 1ST & 2ND SHAPE:

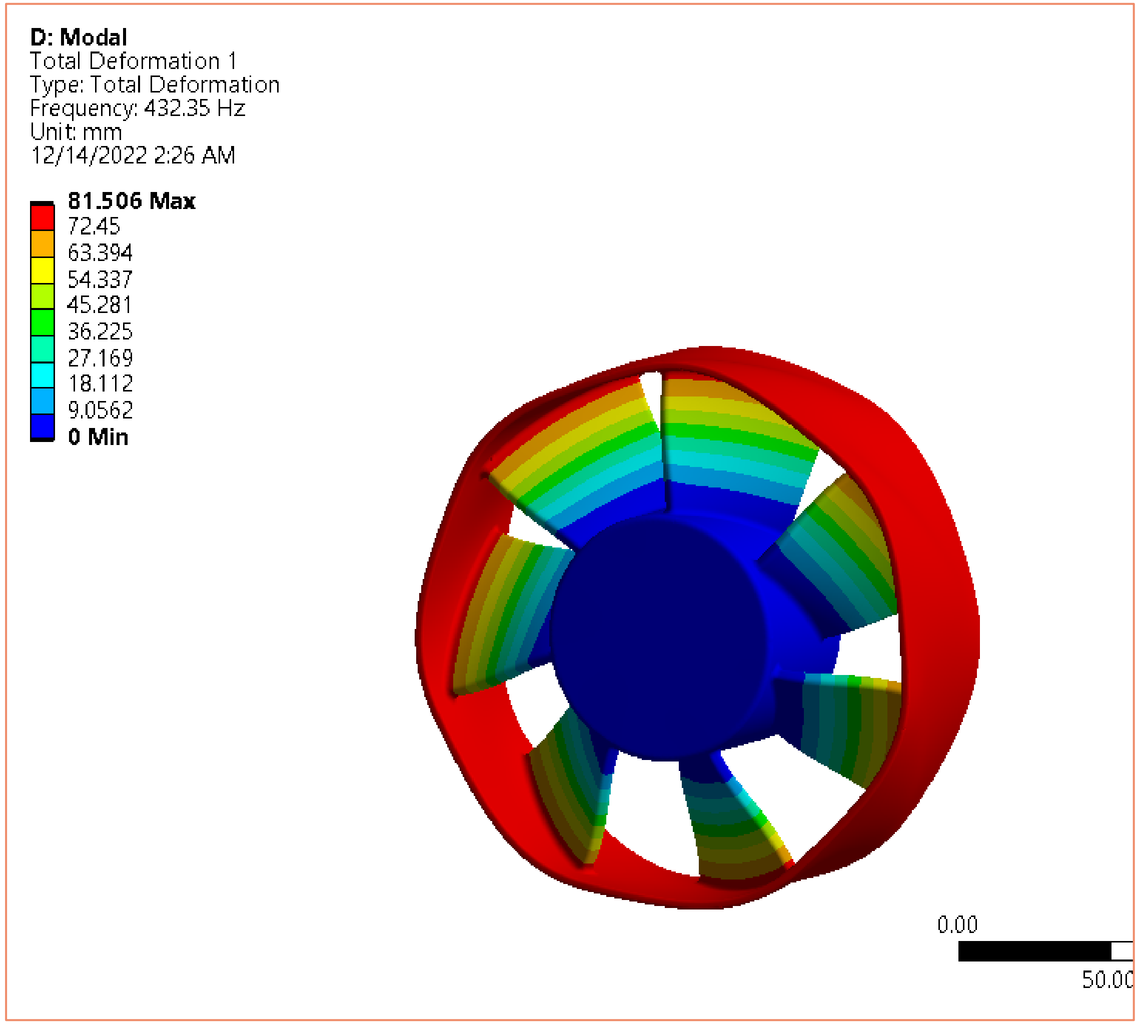


Fig. Mode 1

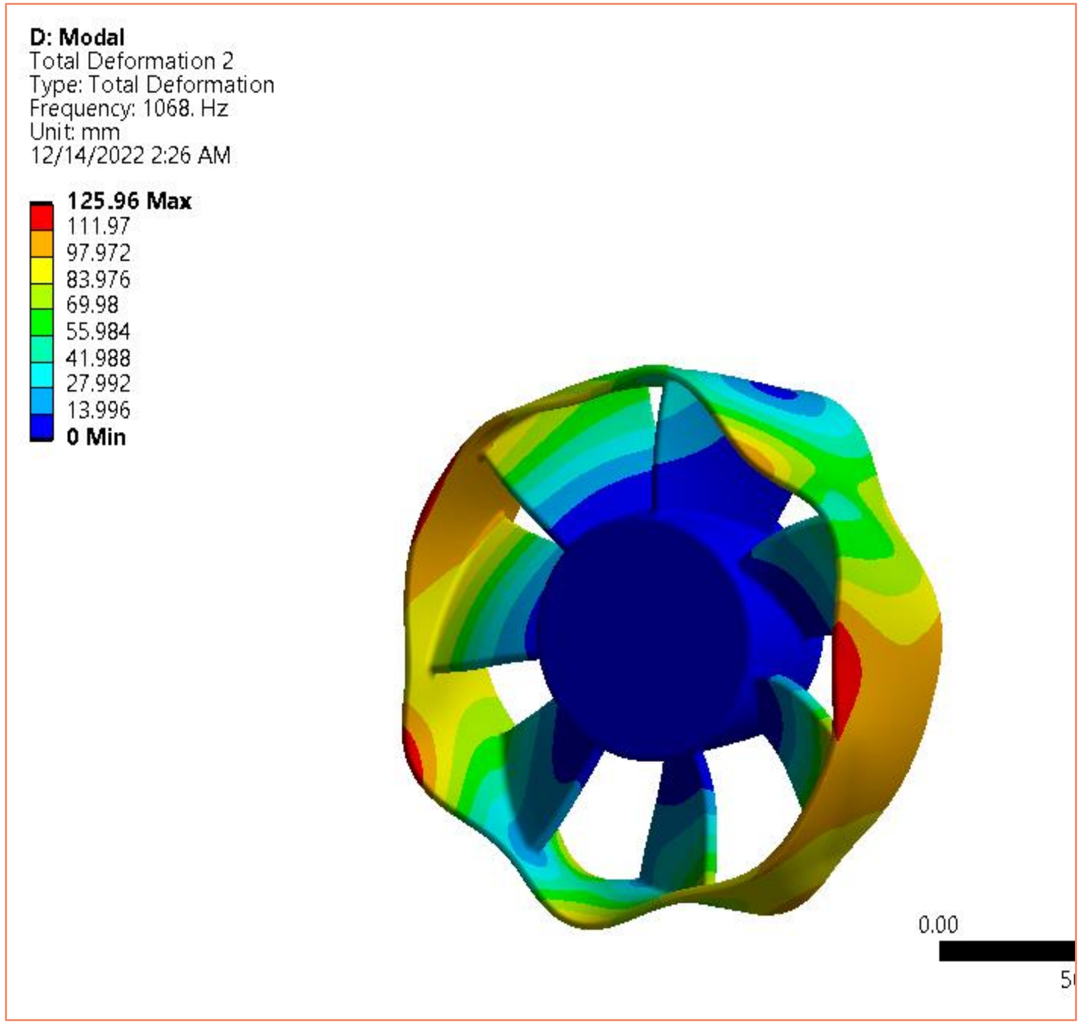


Fig. Mode 2

RESULTS FOR FAN-MODAL ANALYSIS 3RD & 4TH SHAPE:

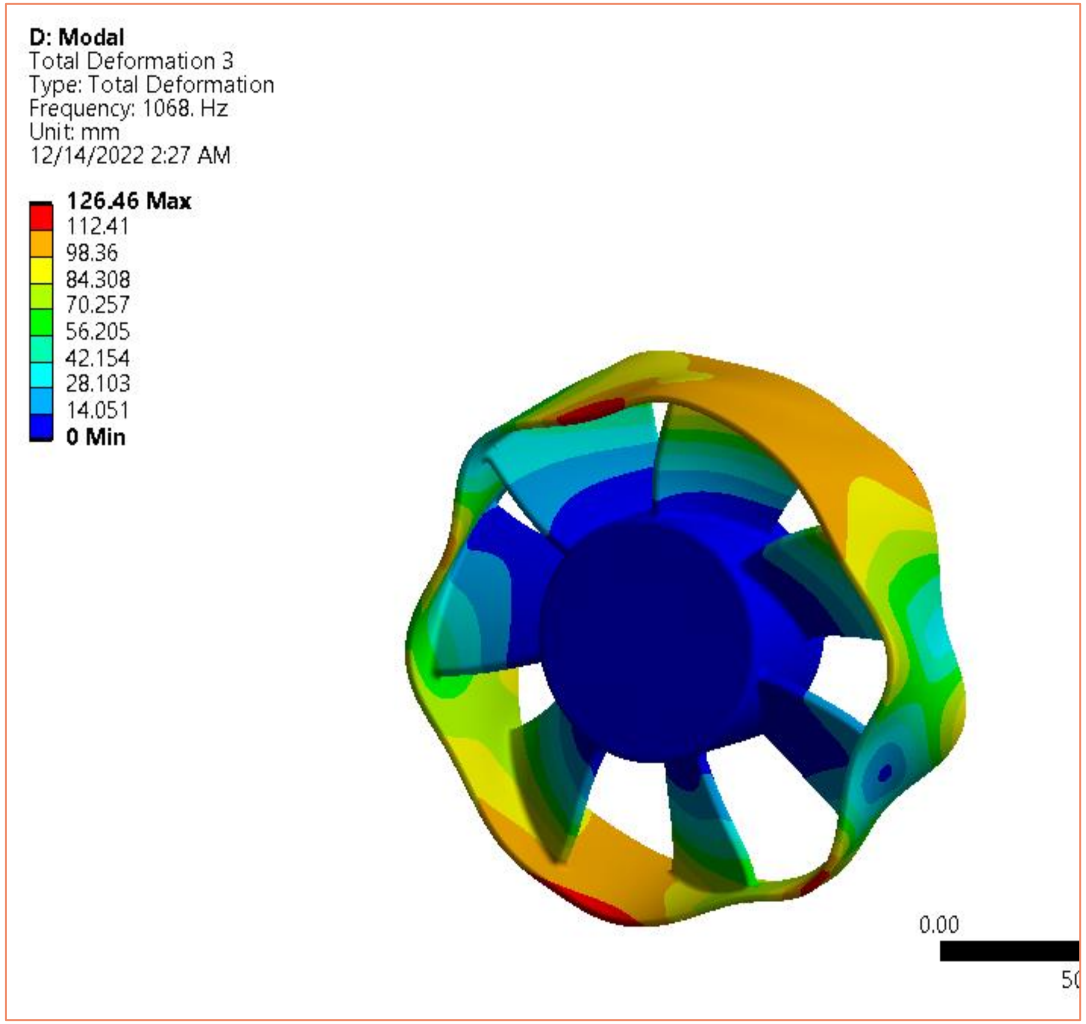


Fig. Mode 3

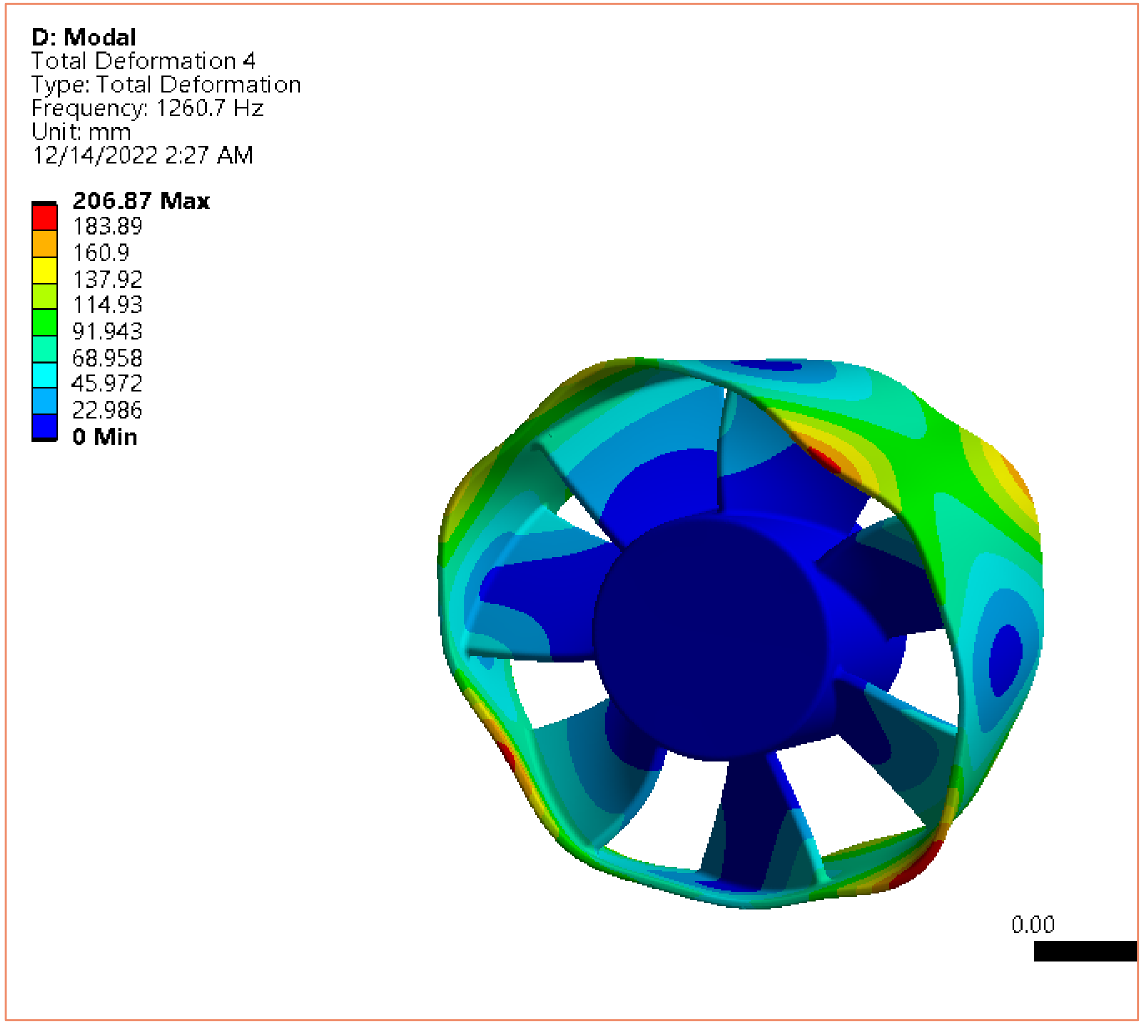


Fig. Mode 4

RESULTS FOR FAN-MODAL ANALYSIS 5TH & 6TH SHAPE:

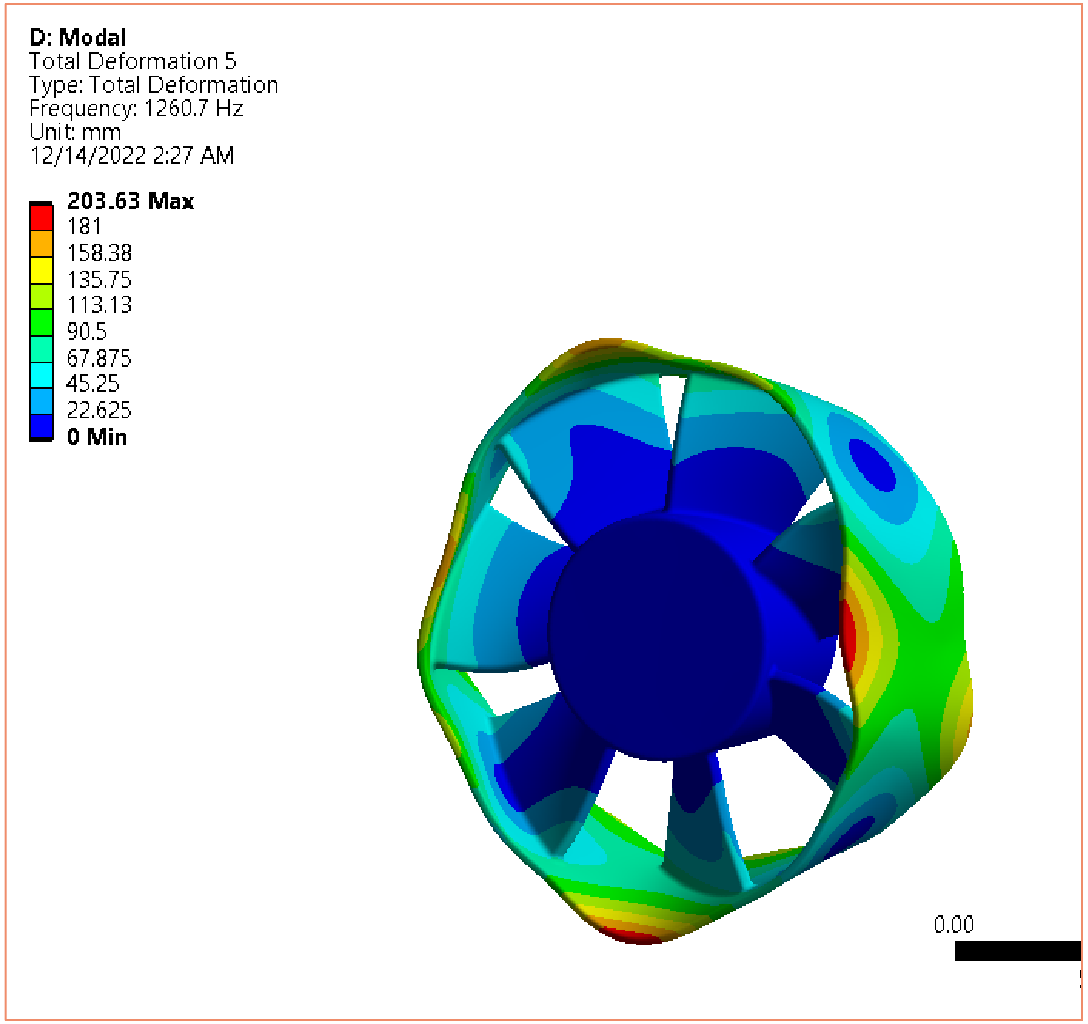


Fig. Mode 5

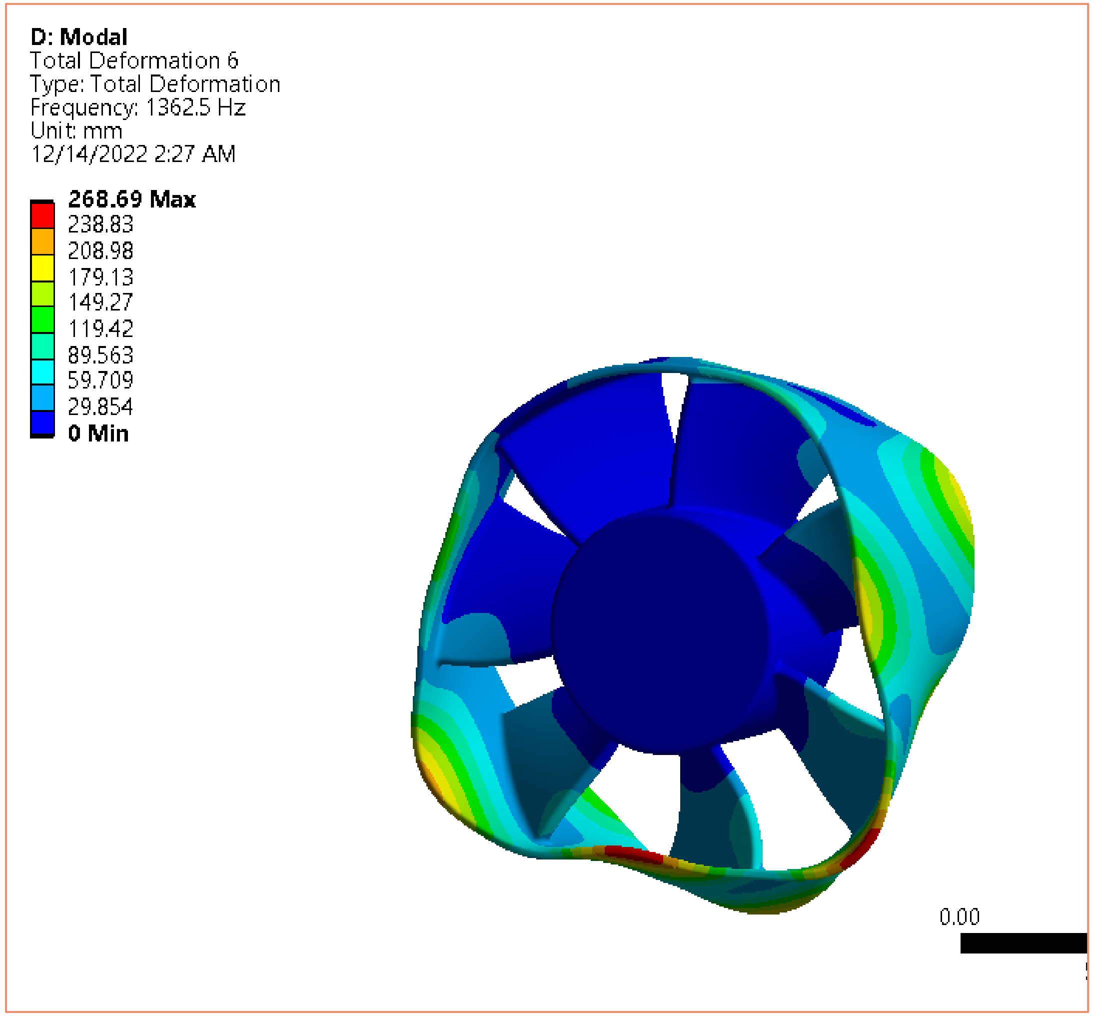


Fig. Mode 6

DISCUSSION ON MODAL ANALYSIS:

Assume that the natural frequency of the first mode is too high, and we would like to reduce that in half. What would you recommend to change (without changing the design) so we can cut the natural frequency in half?

$$w_n = \sqrt{\frac{k}{m}}$$

Where we know that, **k** = stiffness**, m** = mass

- ❖ As we all know that the natural frequency is directly proportional to the stiffness and indirectly proportional to the mass.
- ❖ In order to reduce the natural frequency into half, we could either decrease the stiffness or increase the mass of the given material.
- ❖ We can change the material of the fan blade which is less dense or that has a greater stiffness, so that we can cut the natural frequency in half.

THANK YOU FOR READING !!!