Design and Analysis of a Composite Fan Blade

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Abstract: - The present work is directed towards the study of aircraft engine cooling fan working and its terminology, simulation of cooling fan has been performed. To analyse the cooling fan in ANSYS software. Static analysis is to determine the deformation, stress and strain of the propeller blade. The optimizing of the cooling fan and the material chromium steel, carbon fibre and honeycomb structure, 3D modeling done in CATIA software.

Keywords:- Overabundance, Radiator fan, Fills, ANSYS software, CATIA software

1. Introduction

A mechanical fan is a powered machine used to create flow within a fluid, typically a gas such as air. Most fans are powered by electric motors, but other sources of power may be used, including hydraulic motors, hand cranks, internal combustion engines, and solar power. A fan consists of a rotating arrangement of vanes or blades and hub is known as an impeller, a rotor, or a runner, usually, it is contained within some form of housing or case. Mechanically, a fan can be any revolving vane or vanes used for producing currents of air. A fan blade will often rotate when exposed to an air fluid stream, and devices that take advantage of this, such as anemometers and wind turbines, often have designs similar to that of a fan. Typical applications include climate control and personal thermal comfort (e.g., an electric table or floor fan), vehicle engine cooling systems (e.g., in front of a radiator), machinery cooling systems (e.g., inside computers and audio power amplifiers), ventilation, fume extraction, winnowing (e.g., separating chaff of cereal grains), removing dust (e.g., sucking as in a vacuum cleaner), drying (usually in combination with a heat source) and to provide draft for a fire.

2. Literature survey

This paper addresses the structural analysis and optimization of a composite sandwich ply lay-up of a NASA baseline solid metallic fan blade comparable to a future Boeing 737 MAX aircraft engine. Sandwich construction with a polymer matrix composite face sheet and honeycomb aluminium core replaces the original baseline solid metallic fan model made of Titanium. The ply lay-up of the blade is adjusted from

the calculated number of plies and final structural analysis is performed. Analyses were carried out by utilizing the Open MDAO Framework, developed at NASA Glenn Research Centre combining optimization with structural assessment. A composite fan blade is a fan blade made of composite materials such as carbon fiber reinforced polymer (CFRP) or glass fibre reinforced polymer (GFRP). The aerodynamic and structural viability of composite fan blades of the revolutionary Exo-Skeletal [1] is a revolutionary engine design developed at NASA Glenn Research Centre to meet the increasingly demanding specifications for next generation jet engines. The Exo-Skeletal fan blades' aerodynamic and structural performance are assessed using the NASA internal computer code EST/BEST [2] (Engine Structures Technology Benefit Estimator). The following modules were used to produce the results shown in this paper: (1) CSPAN [3], which uses span line analysis to determine the components' flow path, initial velocity diagrams, hub radii, and initial blading geometry; (2) Blade [4] design code, which creates a blade shape and calculates flow losses and adiabatic efficiency; (3) Flow [5] code, which evaluates the aerodynamic performance of the designed blade shape and determines the blade surface pressures and temperatures; Evaluation of composite structures by (4) composite modelers[6]; (5) Finite element modelers[7]; (6) finite element analysis[8]; and (7) progressive damage[9] evaluation of composite structures.The fan rotor overall adiabatic efficiency obtained from aerodynamic analysis is estimated at 91.6 percent. The flow is supersonic near the blade leading edge but quickly transitions into a subsonic flow without any turbulent boundary layer separation on the blade. The structural evaluation of the composite fan blade indicates that the blade would buckle at a rotor speed that is 3.5 times the design speed of 2000 rpm. This composite cutting edge has more strength over existing fan edge. The current fan cutting edge weighs about 295 grams while the heaviness of composite fan edge is 215grams, which is 28% lesser than existing edge. So, when we utilize composite fan implies, we can decrease 30% of force devoured by the current roof fan. Cost of composite roof fan cutting edge is Rs. From the review, it is presumed that fiber built up plastic material is an appropriate material for assembling the composite roof fan cutting edge. The Fan blade have been the most common engineering part which are used by everyone in everyday life. The increasing population and technology have made the use of fan blade a priority and the fan blades used today.

3. WORK ANALYSIS

Static Analysis of fan blade

Material – <u>CHROMIUM STEEL</u>

Young’s modulus = 205000mpa

Poisson’s ratio = 0.33

Density = 7850 kg/mm3

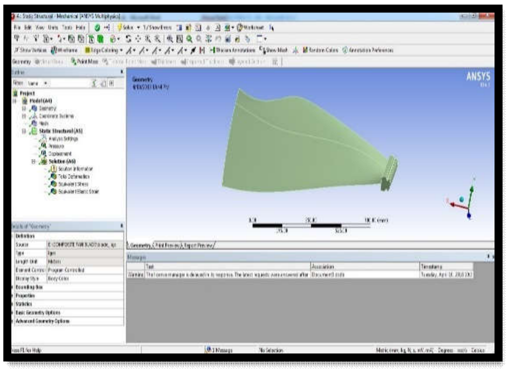


Fig 1: Design of fan blade

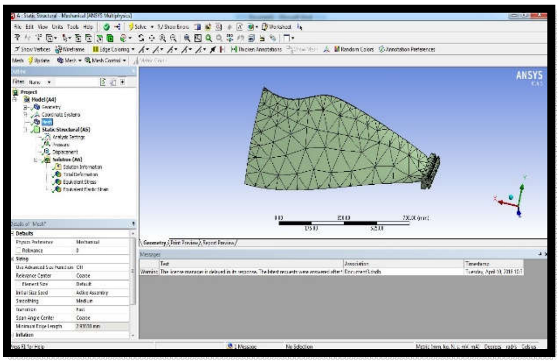


Fig 2: Meshing of fan blade

<u>DEFINATIONS</u>

TOTAL DEFORMATION: - It is defined as the square root of the total of the square of X, Y&Z direction, mathematically it can be written as, Total deformation = SQRT(X^2+Y^2+Z^2) (X, Y, Z are directional deformations)

VON – MISES STRESS: - It is a value used to determine if a given material will yield or fracture. It is mostly used for Ductile materials, such as metals. The von Mises yield criterion states that if the von Mises stress of a material under a load is equal to or greater than the yield limit of the same material under simple tension then the material will yield.

VON – MISES STRAIN: - It is often termed as the equivalent plastic strain.

PLASTIC STRAIN: - Strain in which the distorted body does not return to its original size and shape after the deforming force has been removed

SPECIFICATIONS

MATERIAL	COMPOSITION
CHROMIUM STEEL	The high chrome alloy steel material contains the following chemical elements by mass percent: 2.6-2.8% of carbon, 11.3-12.5% of chrome, 0.1-0.3% of nickel, 0.3-0.5% of manganese, 0.04-0.06% of molybdenum, 0.3-0.5% of vanadium, 0.005-0.006% of titanium, 0.7-0.8% of copper, not more than 0.03% of P, not more than 0.03% of S and the balance of iron.
CARBON FIBRE	About 90% of the carbon fibers produced are made from polyacrylonitrile (PAN). The remaining 10% are made from rayon or petroleum pitch.
HONEYCOMB STRUCTURE	Honeycomb structure is manufactured by the usage of materials such as glass-reinforced plastic (also known as fiberglass), carbon fiber reinforced plastic, Nomex aramid paper reinforced plastic, or from a metal (usually aluminium).

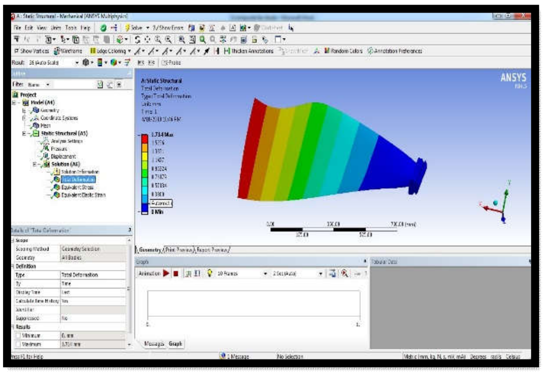


Fig 3: Total Deformation

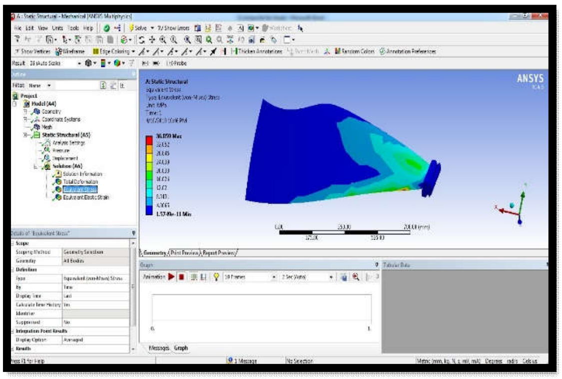


Fig 4: Von – Mises Stress

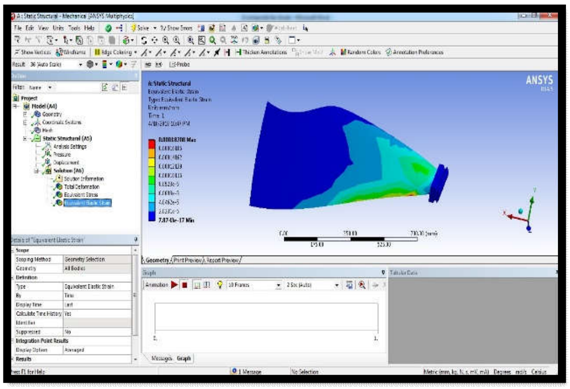


Fig 5: Von – Mises Strain

Material - <u>CARBON FIBER</u>

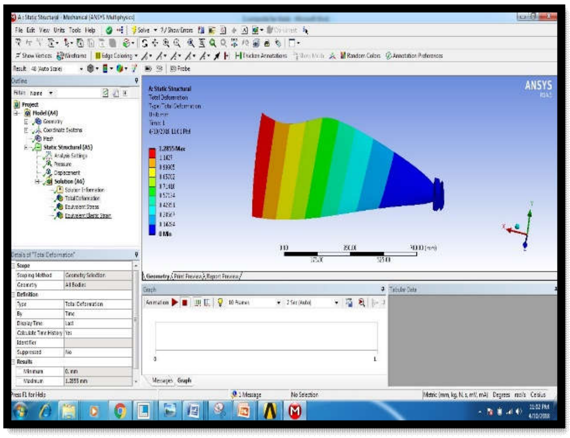


Fig 6: Total Deformation

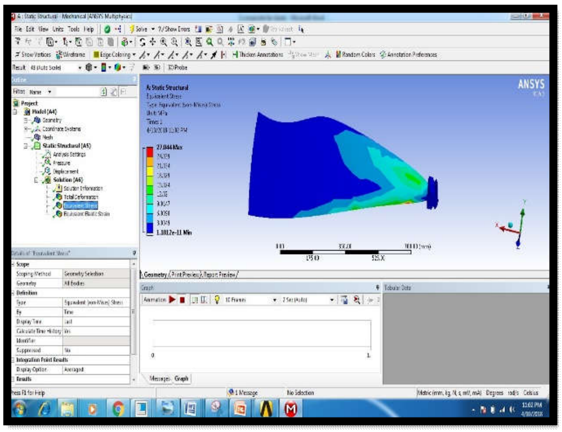


Fig 7: Von – Mises Stress

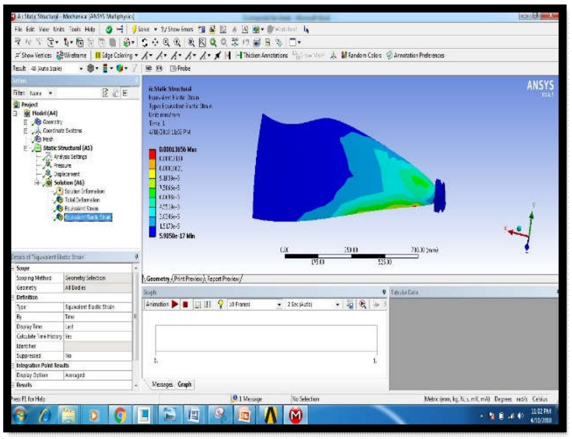


Fig 8: Von – Mises Strain

Material - HONEY COMB STRUCTURE

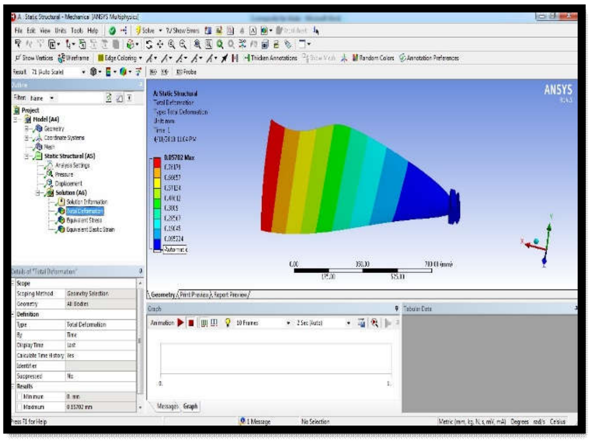


Fig 9: Total Deformation

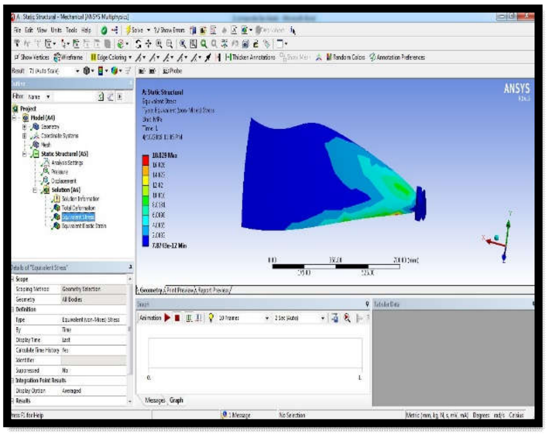


Fig 10: Von – Mises Stress

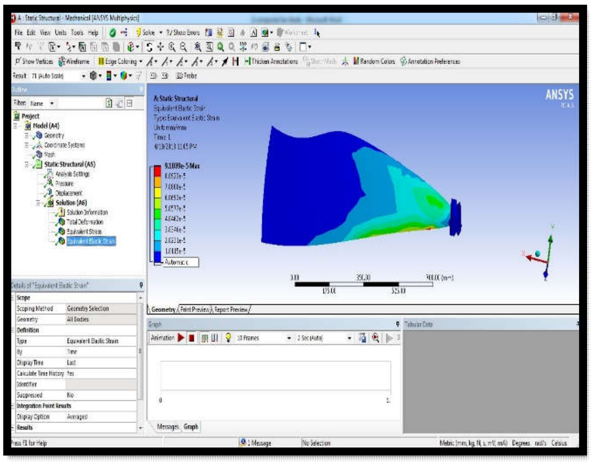


Fig 11: Von – Mises Strain

Modal Analysis of composite fan blade

Material - CHROMIUM STEEL

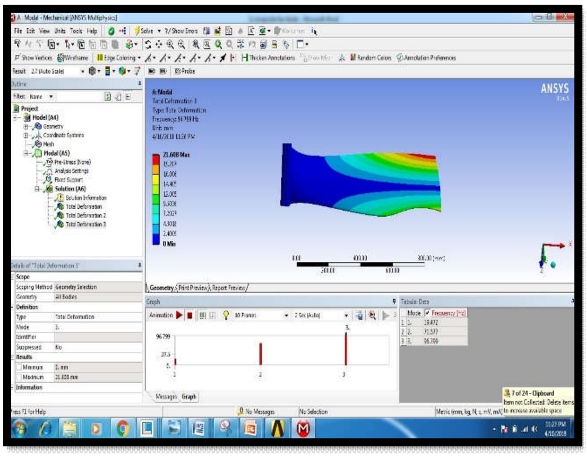


Fig 12: Total Deformation I

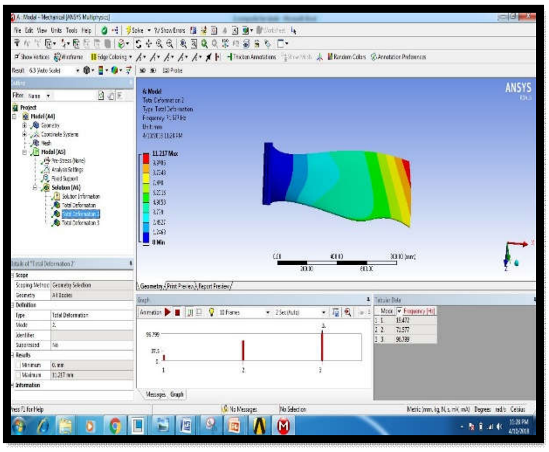
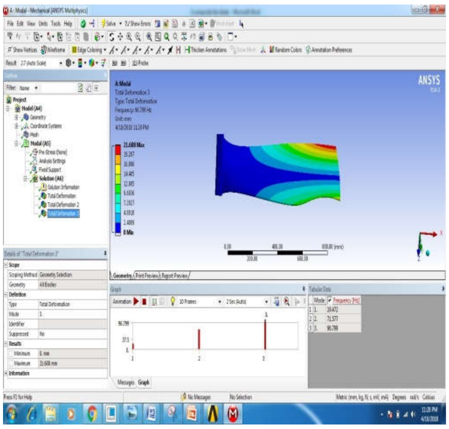


Fig 13: Total Deformation II

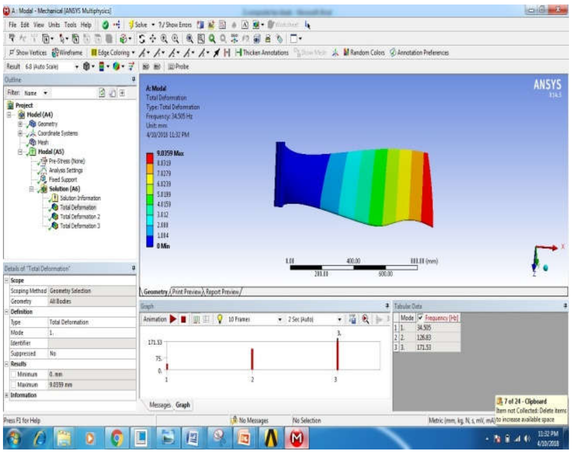


A: Modal
Total Deformation 3
Type: Total Deformation
Frequency: 96.799 Hz
Unit: mm
4/10/2018 11:28 PM

	Mode	Frequency [Hz]
1	1.	19.472
2	2.	73.577
3	3.	96.799

Fig 14: Total Deformation III

Material - CARBON FIBER

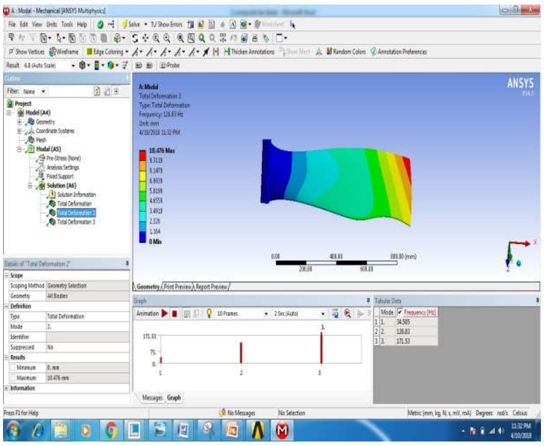


A: Modal
Total Deformation
Type: Total Deformation
Frequency: 34.505 Hz
Unit: mm
4/10/2018 11:32 PM

	Mode	Frequency [Hz]
1	1.	34.505
2	2.	126.83
3	3.	171.53

7 of 24 - Clipboard
Item not Collected: Delete items to increase available space

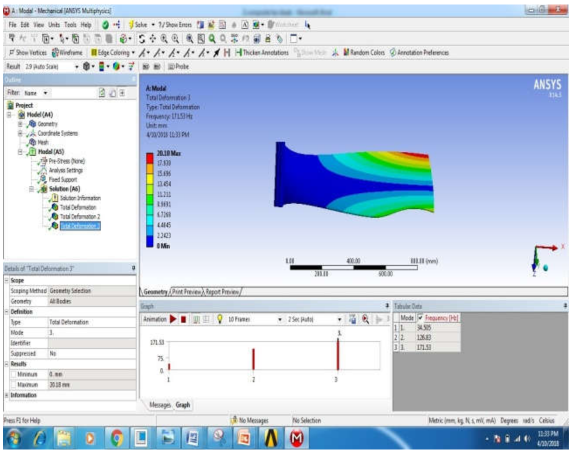
Fig 15: Total Deformation I



A: Modal
Total Deformation 2
Type: Total Deformation
Frequency: 126.83 Hz
Unit: mm
4/10/2018 11:32 PM

	Mode	Frequency [Hz]
1	1.	34.505
2	2.	126.83
3	3.	171.53

Fig 16: Total Deformation II



A: Modal
Total Deformation 3
Type: Total Deformation
Frequency: 171.53 Hz
Unit: mm
4/10/2018 11:33 PM

	Mode	Frequency [Hz]
1	1.	34.505
2	2.	126.83
3	3.	171.53

Fig 17: Von-Mises Strain

Material - HONEY COMB STRUCTURE

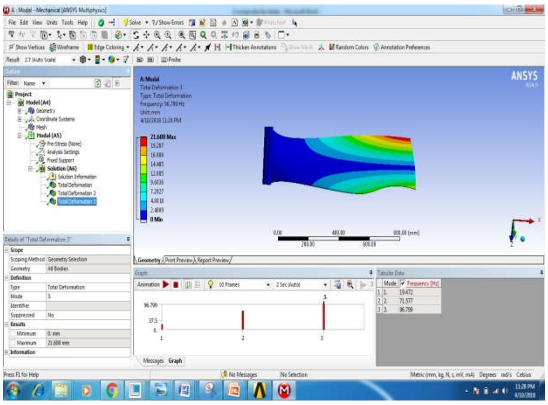


Fig 18: Total Deformation

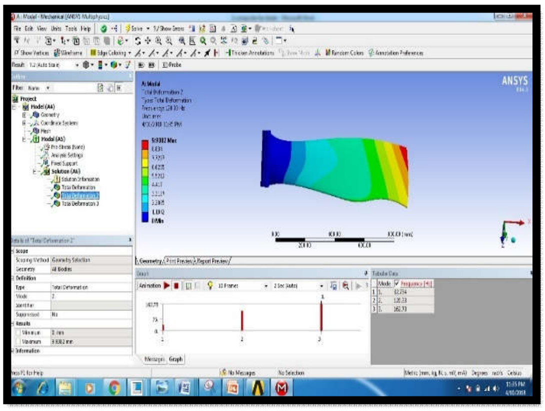


Fig 19: Von-Mises Stress

Fig 20: Von-Mises Strain

Thermal Analysis of composite fan blade

Material - CHROMIUM STEEL

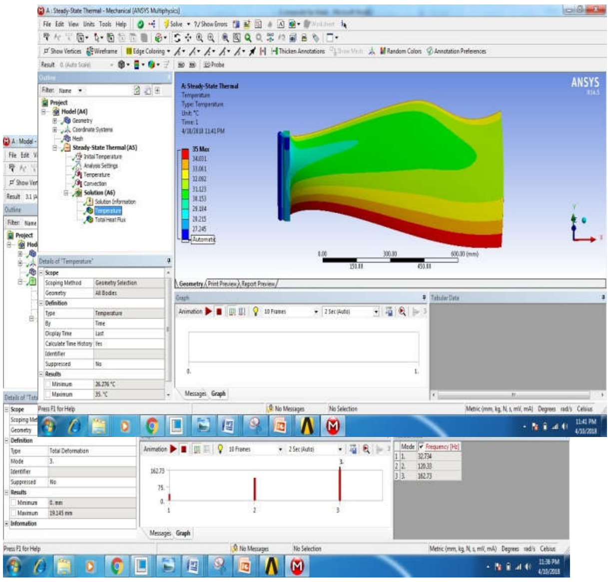


Fig 21: Temperature

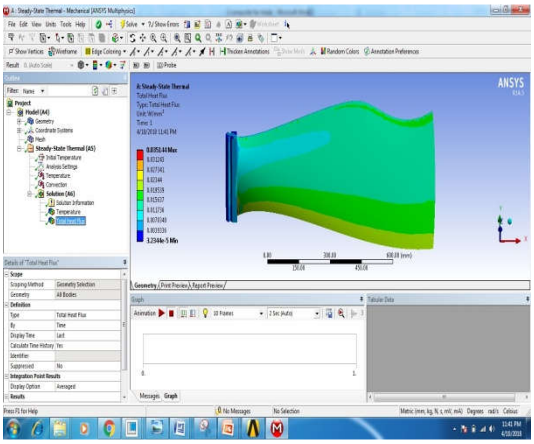


Fig 22: Heat Flux

Material - CARBON FIBER

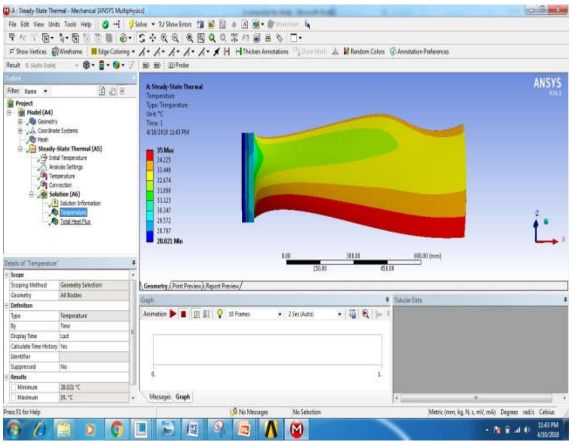


Fig 23: Temperature

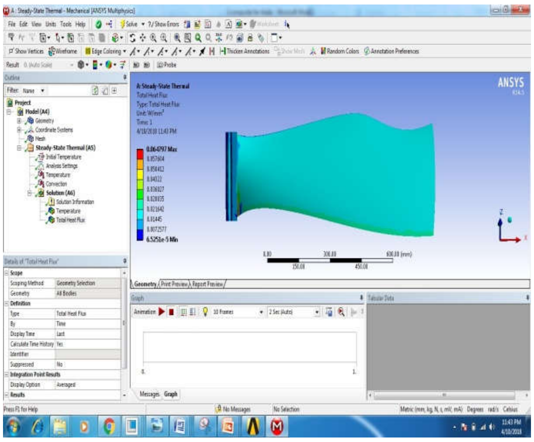


Fig 24: Heat Flux

Material - HONEY COMB

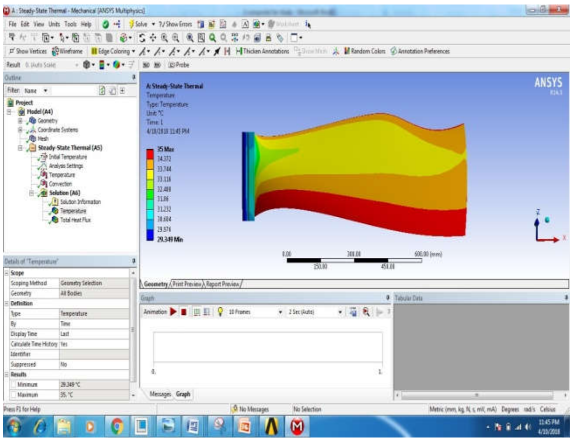


Fig 25: Temperature

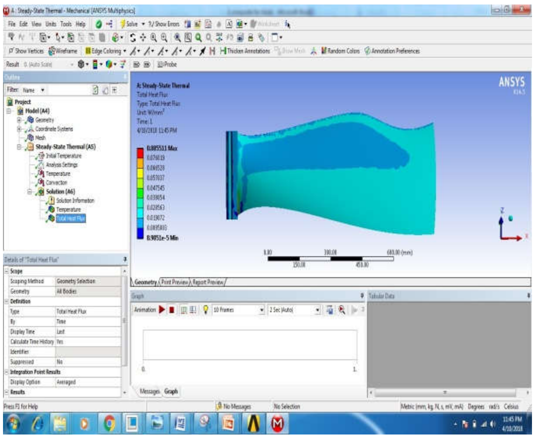
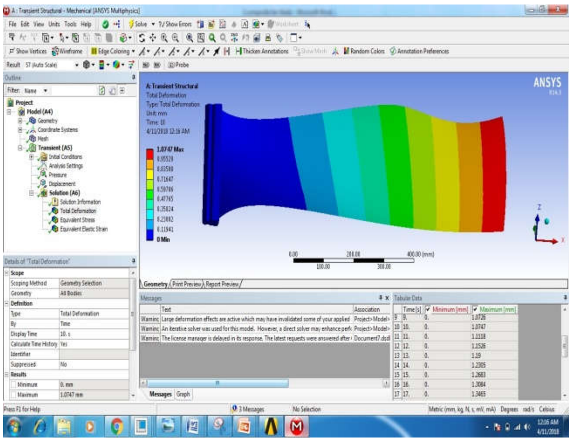


Fig 26: Heat Flux

Dynamic Analysis of composite fan blade

AT TIME -10SEC

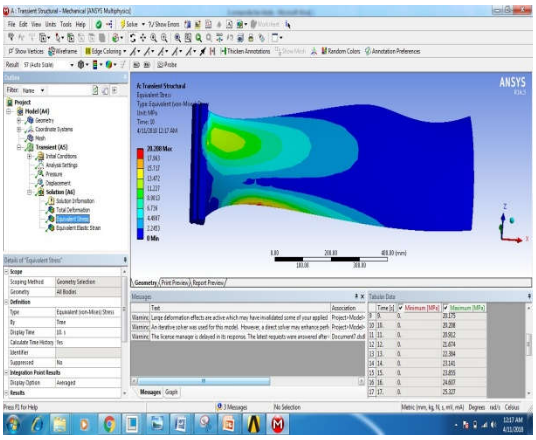


Warning: Large deformation effects are active which may have invalidated some of your applied

Warning: An iterative solver was used for this model. However, a direct solver may enhance perf

Warning: The license manager is delayed in its response. The latest requests were answered after

Fig 27: Total Deformation

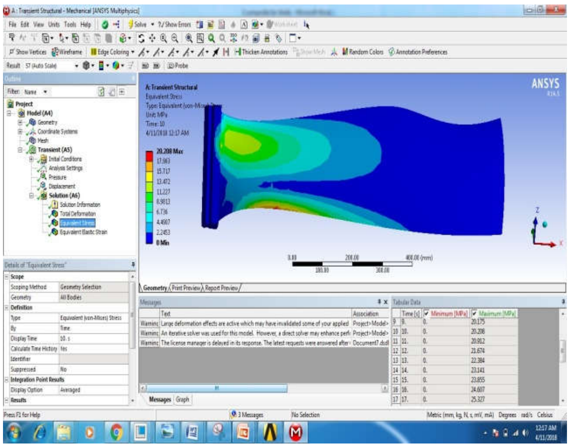


Warning: Large deformation effects are active which may have invalidated some of your applied

Warning: An iterative solver was used for this model. However, a direct solver may enhance perf

Warning: The license manager is delayed in its response. The latest requests were answered after

Fig 28: Von0Mises Stress



A: Transient Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 10
4/11/2018 12:17 AM

Details of "Equivalent Stress"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Equivalent (von-Mises) Stress
By	Time
Display Time	10. s
Calculate Time History	Yes
Identifier	
Suppressed	No
Integration Point Results	
Display Option	Averaged
Results	

Messages

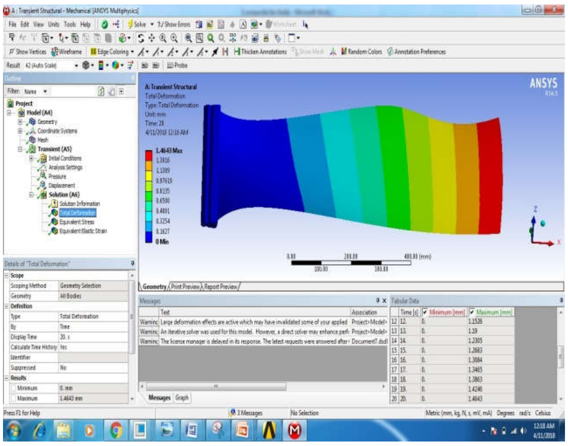
	Text	Association
Warning	Large deformation effects are active which may have invalidated some of your applied	Project>Model>
Warning	An iterative solver was used for this model. However, a direct solver may enhance perf	Project>Model>
Warning	The license manager is delayed in its response. The latest requests were answered after	Document7.dsdl

Tabular Data

	Time [s]	☑ Minimum [MPa]	☑ Maximum [MPa]
9	9.	0.	20.175
10	10.	0.	20.208
11	11.	0.	20.912
12	12.	0.	21.674
13	13.	0.	22.384
14	14.	0.	23.141
15	15.	0.	23.855
16	16.	0.	24.607
17	17.	0.	25.327

Fig 29: Von-Mises Strain

AT TIME -20SEC



A: Transient Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 20
4/11/2018 12:18 AM

Details of "Total Deformation"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Total Deformation
By	Time
Display Time	20. s
Calculate Time History	Yes
Identifier	
Suppressed	No
Results	
☐ Minimum	0. mm
☐ Maximum	1.4643 mm

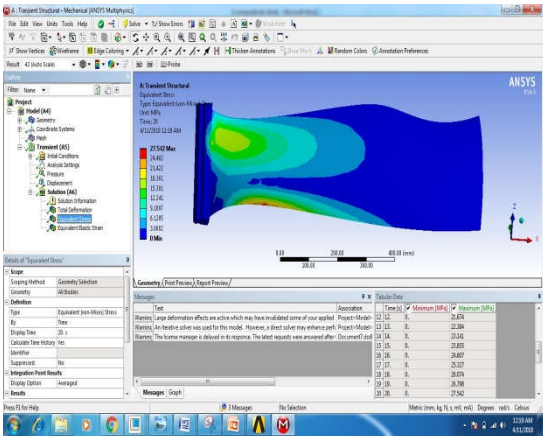
Messages

	Text	Association
Warning	Large deformation effects are active which may have invalidated some of your applied	Project>Model>
Warning	An iterative solver was used for this model. However, a direct solver may enhance perf	Project>Model>
Warning	The license manager is delayed in its response. The latest requests were answered after	Document7.dsdl

Tabular Data

	Time [s]	☑ Minimum [mm]	☑ Maximum [mm]
12	12.	0.	1.1526
13	13.	0.	1.19
14	14.	0.	1.2305
15	15.	0.	1.2683
16	16.	0.	1.3084
17	17.	0.	1.3465
18	18.	0.	1.3863
19	19.	0.	1.4246
20	20.	0.	1.4643

Fig 30: Total Deformation



A: Transient Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 20
4/11/2018 12:18 AM

Details of "Equivalent Stress"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Equivalent (von-Mises) Stress
By	Time
Display Time	20. s
Calculate Time History	Yes
Identifier	
Suppressed	No
Integration Point Results	
Display Option	Averaged
Results	

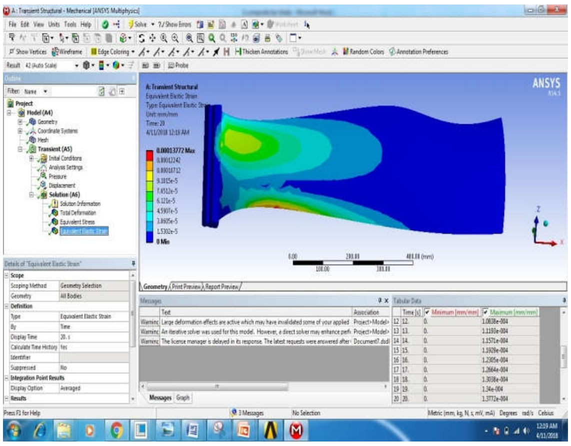
Messages

	Text	Association
Warning	Large deformation effects are active which may have invalidated some of your applied	Project>Model>
Warning	An iterative solver was used for this model. However, a direct solver may enhance perf	Project>Model>
Warning	The license manager is delayed in its response. The latest requests were answered after	Document7.dsdl

Tabular Data

	Time [s]	☑ Minimum [MPa]	☑ Maximum [MPa]
12	12.	0.	21.674
13	13.	0.	22.384
14	14.	0.	23.141
15	15.	0.	23.855
16	16.	0.	24.607
17	17.	0.	25.327
18	18.	0.	26.074
19	19.	0.	26.798
20	20.	0.	27.542

Fig 31: Von-Mises Stress



A: Transient Structural
Equivalent Elastic Strain
Type: Equivalent Elastic Strain
Unit: mm/mm
Time: 20
4/11/2018 12:19 AM

Details of "Equivalent Elastic Strain"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Equivalent Elastic Strain
By	Time
Display Time	20. s
Calculate Time History	Yes
Identifier	
Suppressed	No
Integration Point Results	
Display Option	Averaged
Results	

Messages

	Text	Association
Warning	Large deformation effects are active which may have invalidated some of your applied	Project>Model>
Warning	An iterative solver was used for this model. However, a direct solver may enhance perf	Project>Model>
Warning	The license manager is delayed in its response. The latest requests were answered after	Document7.dsdl

Tabular Data

	Time [s]	☑ Minimum [mm/mm]	☑ Maximum [mm/mm]
12	12.	0.	1.0838e-004
13	13.	0.	1.1193e-004
14	14.	0.	1.1571e-004
15	15.	0.	1.1929e-004
16	16.	0.	1.2305e-004
17	17.	0.	1.2664e-004
18	18.	0.	1.3038e-004
19	19.	0.	1.34e-004
20	20.	0.	1.3772e-004

Fig 32: Von-Mises Strain

CFD Analysis of fan blade

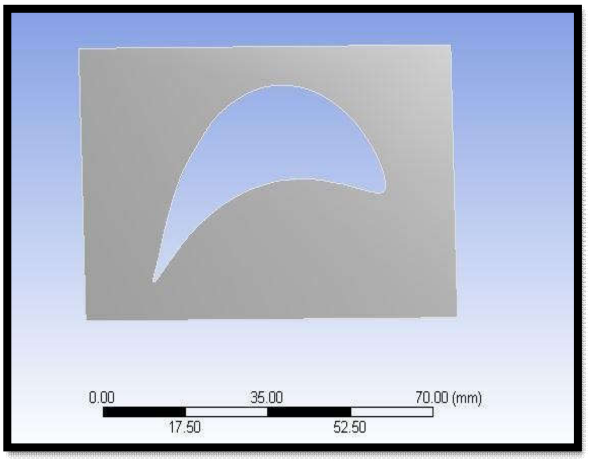


Fig 33: Pro-E model of fan blade

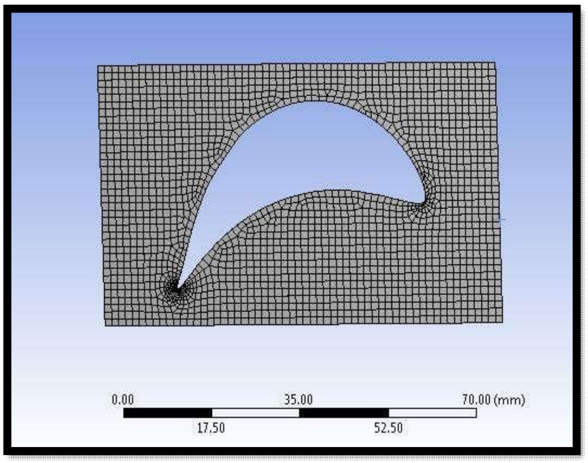


Fig 34: Meshing of fan blade for CFD analysis

Specifying boundaries for Inlet and Outlet

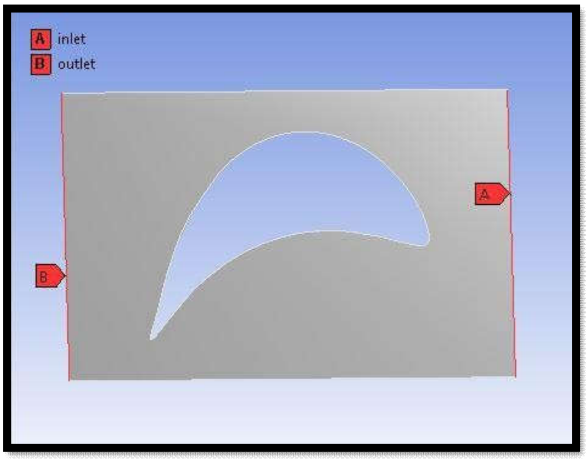
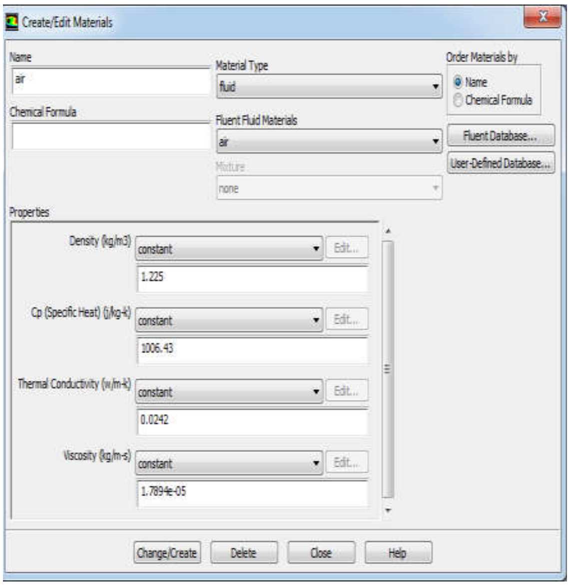


Fig 35: Inlet & Outlet



Name: air

Chemical Formula:

Material Type: fluid

Fluent Fluid Materials: air

Mixture: none

Order Materials by: ● Name ○ Chemical Formula

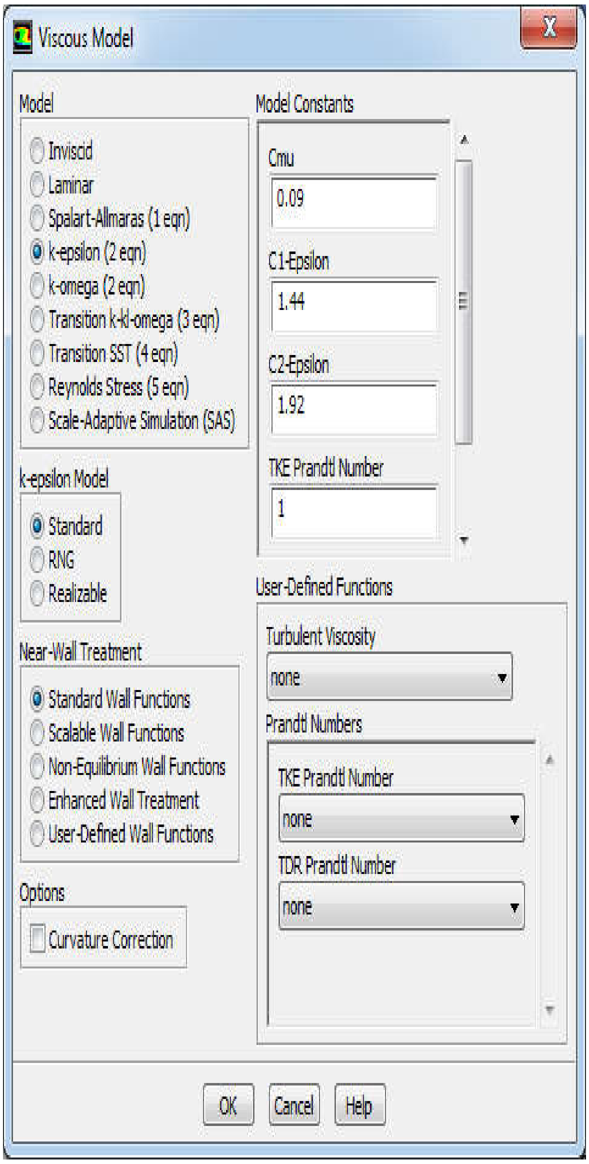
Properties

Density (kg/m3): constant — 1.225

Cp (Specific Heat) (j/kg-k): constant — 1006.43

Thermal Conductivity (w/m-k): constant — 0.0242

Viscosity (kg/m-s): constant — 1.7894e-05



Model

○ Inviscid
○ Laminar
○ Spalart-Allmaras (1 eqn)
● k-epsilon (2 eqn)
○ k-omega (2 eqn)
○ Transition k-kl-omega (3 eqn)
○ Transition SST (4 eqn)
○ Reynolds Stress (5 eqn)
○ Scale-Adaptive Simulation (SAS)

k-epsilon Model

● Standard
○ RNG
○ Realizable

Near-Wall Treatment

● Standard Wall Functions
○ Scalable Wall Functions
○ Non-Equilibrium Wall Functions
○ Enhanced Wall Treatment
○ User-Defined Wall Functions

Options

☐ Curvature Correction

Model Constants

Cmu: 0.09

C1-Epsilon: 1.44

C2-Epsilon: 1.92

TKE Prandtl Number: 1

User-Defined Functions

Turbulent Viscosity: none

Prandtl Numbers

TKE Prandtl Number: none

TDR Prandtl Number: none

Fig 36: Specifying Boundaries

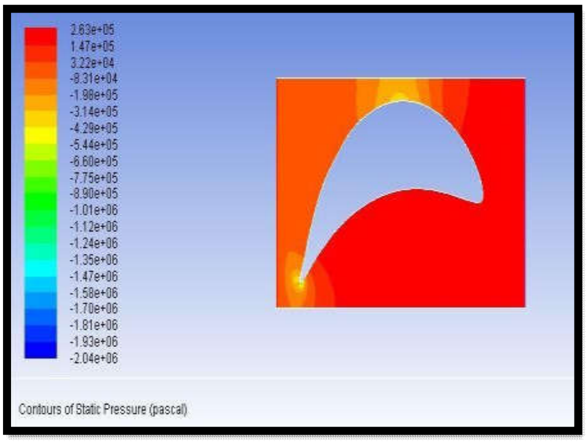


Fig 37: Pressure

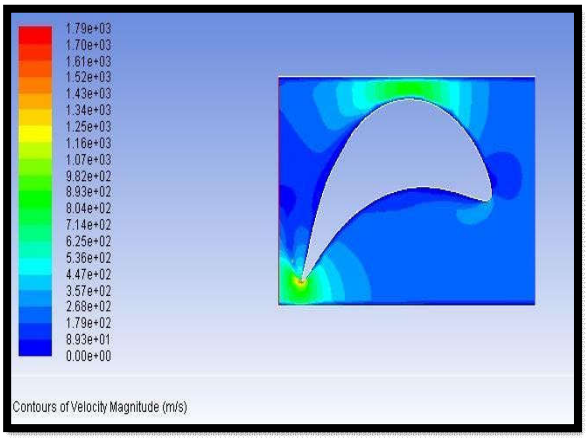


Fig 38: Velocity

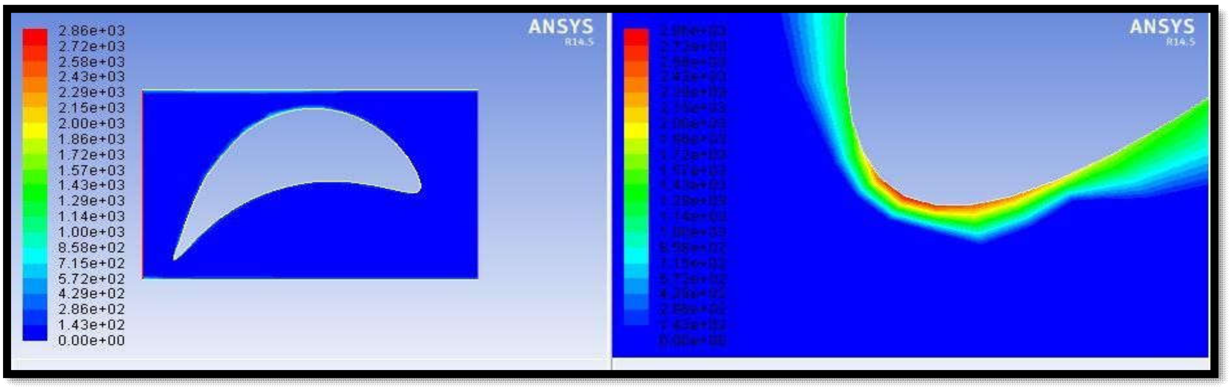
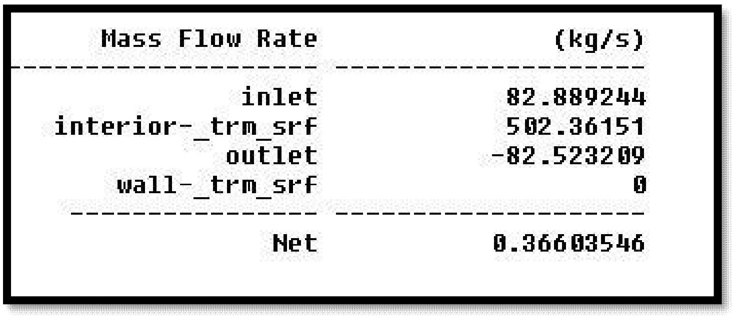
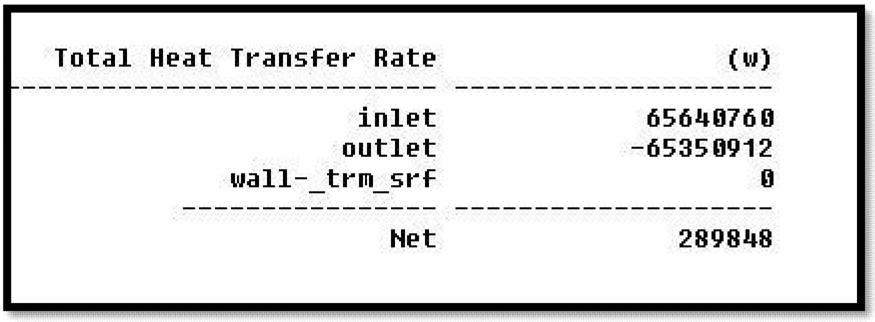


Fig 39: Heat Transfer Coefficient



```
        Mass Flow Rate                 (kg/s)
-------------------- --------------------
                 inlet              82.889244
   interior-_trm_srf              502.36151
                outlet             -82.523209
          wall-_trm_srf                      0
    ---------------- --------------------
                   Net             0.36603546
```

Fig 40: Mass Flow Rate



```
  Total Heat Transfer Rate                    (w)
---------------------------- --------------------
                       inlet               65640760
                      outlet              -65350912
               wall-_trm_srf                      0
      ---------------- --------------------
                         Net                 289848
```

Fig 41: Heat Transfer Rate

4. Experimental plan

Therefore, the experiments were carried out using the software's: CATIA (Computer Aided Three-Dimensional Interactive Application), CREO, ANSYS (Analysis of Systems), CAD (Computer Aided Design).

S.NO	SOFTWARE	**SPECIFICATION**	**USAGE**
1	AUTOCAD	AUTOCAD 2021 Version 24.0	2D Design
2	CREO	PTC Creo 3.0	3D Modelling
3	ANSYS	Ansys 22.2	Analysis
4	CATIA	Catia V5R18	Rendering Technology and Sketching

5. Results & Discussion

Results of Static Analysis

After the static analysis of the 3 different materials; chromium steel, carbon fibre and honeycomb structure. Three static analysis tests are carried out (1) Deformation Test, (2) Stress Test and (3) Strain Test accordingly. Each material behaves differently, Chromium steel giving a deformation of 1.714 mm, stress of 36.059 N/mm^2 and a strain of 0.00018208 mm. Carbon fibre gives a deformation of 2.855 mm, stress of 27.044 N/mm^2 and a strain of 0.000133656 mm. And finally honeycomb structure gives a deformation of 0.85702 mm, stress of 18.029 N/mm^2 and a strain of 9.1039e-5 mm. From the static analysis tests, we can clearly see the **honeycomb structure** performing the best out of the 3.

Results of Modal Analysis

From the modal analysis of the three different materials, we determine the vibration characteristics of them respectively. Modal analysis looks for the natural frequencies of the material and how they respond to different dynamic loads. Here three different modes are conducted to check output of their frequencies respectively. Chromium steel; 19.472, 71.577 & 96.799 in the 3 different modes. Carbon fibre; 34.505, 126.83 & 171.53. Finally Honeycomb structure; 32.734, 120.83, 162.73. From the results of modal analysis, we can identify that **honeycomb structure** is able to withstand higher dynamic loads or vibration.

Results of Thermal Analysis

Thermal analysis is conducted to provide deeper insights into a material's behaviour with different temperature scenarios and to predict how their products will perform with temperature changes. Here we test for the minimum and maximum temperature range of the materials and their heat flux as well. Chromium steel has a minimum of 26.276 and a maximum of 35 and a heat flux value of 0.03514. Carbon fibre has a minimum of 28.209 and a maximum of 35 and a heat flux value of 0.064797.

Honeycomb structure has a minimum of 29.349 and a maximum of 35 and a heat flux value of 0.08511. From the values of acquired after the thermal analysis has been completed, we can deduce that **honeycomb structure** performs the best as the amount of heat transferred by it is greater than the two other materials.

6. CONCLUSIONS

- The present work is directed towards the study of air craft engine cooling fan working and its terminology, simulation of cooling fan has been performed. To analyze the cooling fan in ANSYS software
- Static and thermal is to determine the deformation, stress, strain, temperature and heat flux ofthe marine composite fan blade.
- The optimizing the cooling fan varying the blades and also optimizing the material chromiumsteel carbon fiber honey comb structure. 3D modeling done in CATIA software
- By observing thermal analysis heat flux is more for **honeycomb structure** so it is better to compare to the remaining materials

7. REFERENCES

1. I. Halliwell, Exo-Skeletal Engine Concept: Feasibility Studies for Medium and Small Thrust Engines, NASA Contractor Report 2001ñ211322.

2. G.H. Abumeri and C.C. Chamis, EST/BEST: A Computer Code for Assessing the Benefits of Advanced Aerospace Technologies, Journal of Advances in Engineering Software, 1997 Elsevier Science Limited, Printed in Great Britain., pp. 231ñ238.

3. A.J. Glassman and T.M. Lavelle, Enhanced Capabilities and Modified User’s Manual for Axial-Flow Compressor Conceptual Design code CSPAN, NASA TMñ106833, January 1995.

4. J.E. Crouse and W.T. Gorrell, Computer Program for Aerodynamic and Blading Design of Multistage Axial-Flow Compressors, NASA TPñ1946, 1981.

5. R.V. Chima, RVCQ3D Rotor Viscous Code 3-D, User’s Manual and Documentation, NASA Glenn Research Center, Cleveland, Ohio, 1999.

6. P.L.N Murthy and C.C. Chamis C.C., Integrated Composite Analyzer (ICAN): Users and Programmers Manual, NASA Technical Paper 2515, 1986.

7. L.R McKnight, R.J. Maffeo and S. Schwartz, Engine Structures Analysis Software: Component Specific Modeling (COSMO), NASA Contractor Report 195378, 1994.

8. S. Nakazawa, J.B. Dias and M.S. Spiegel, The MHOST Finite Element Program: 3-D inelastic analysis Methods for Hot section Components: Volume II-User’s Manual, NASA Contractor Report 182235, 1989. 9. L. Minnetyan, P.L.N. Murthy, and C.C. Chamis, Composite Structure Global Fracture Toughness via Computational Simulation, Computers & Structures, Vol. 37, No. 2, pp. 175ñ180, 1990.