Structural and Vibrational Analysis of Model Aircraft Tapered Wing

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Abstract— The airplane wing design plays very important role to decide the main purpose for which it will be used at the later stage. The design and shape of the wings plays a important role to decide operation for which the plane will be used. Design of Airplane wings are done in such a way that it become the air borne and can produce lift, which will be greater than the weight of the plane including the weight carrying capacity of the airplane. The lift force is required to carry the plane into the air and this lift force is generated by the specific design of the wing of the airplane. Different type of forces acts on the wing which makes the airplane airborne. In order to understand this lifts the combination of Bernoulli's and Newton's Principle helps a lot. The wing of approx every airplane have such a profile in which there is curved at the top and flat at the bottom. This type of designing is done to make the movement of air faster at the bottom which creates the difference in the pressure and results into the generation of lift force. So we can say that the design of wing plays important role to find out the limitation of the airplane. Aircraft wing analysis helps to perform structural and Vibraional analysis of an aircraft wing. Finite element method has been used to formulate the structural and free vibrational analysis on the tapered wing of prototype airplane made up of Balsa wood. ANSYS 12.1 analysis software is used as a mathematical tool in implementation of the analysis and to extract the results and to come on to certain results regarding the wing. Free vibration study represents one of the most important studies for complex structure such as wing structure. In this research, a model for tapper wing structure was created including the airfoil shape using ProE-5 modeling software. The airfoil of the tapper wing is designed using NACA airfoil software. ANSYS 12.1 were the benchmark to proceed for the detailed Structural and Vibrational analysis of the complete tapper wing.

Key words: Aircraft Tapered Wing

I. INTRODUCTION

Airplane is defined as the fixed-wing flying object which is engine-driven and being supported by its wing due to the dynamic reaction of the air against its wings. From the long time flights have been the natural phenomenon and long been the part of natural world. Since it is important to understand some common difference between flights such as smoke also flies or rise thousands of feet high into the air which carries lot of tiny particles. Bird flies in the sky not only by flapping their wings but also can retain into the air for long time by just stretching their wings for example eagles. In the same manner, man-made aircrafts flies into the sky by relying into these amazing principles to move upward against the force of gravitation.

II. LIFT

It is the artificial force which can be manipulated by pilot. It acts perpendicular to the wingspan and the wing and is generated through the wings. Theory which summarizes the force of list and the direction is the center of pressure. It carries the total weight during the cruise level. Greater the lift than weight during climb and reverse is when descents. Formula to find out lift is:

$$\text{Lift} = C_L \times \tfrac{1}{2} \rho v^2 \times s$$

C_L=lift coefficient
S= the airplane wing area
v = an aircraft's velocity
ρ = density of the air.

III. FINITE ELEMENT METHOD

As the numerical method of analysis increase along with the use of high speed computers it causes the finite element method developed. It reduced the time of human being with great accuracy. Science first of all this method was basically developed for the structural analysis and its general nature and easy to access made it also possible to be used in other fields also. So due to its easy to operate and the its general nature made it to be used in other field of engineering. If we talk about the great majority then maximum literature on the FEM is written for the displacement method. One any engineer understand the basics of the FEM then he/she can move to the advance of the FEM other than the structure of soil. In the further expansion of the FEM the theory is generalized so the method can be extended to the other field also.

IV. APPLICATION OF FEM

For any engineering problem it is not possible to find out the analytical mathematical solution. We can say that it is a mathematical solution and it gives the mathematical expression which gives the value of the desired quantity which is unknown to us at any location of the body, for this reason we can say that it is valid for the infinite number of location in any body. This analytical can be obtained for only some of the certain simplified solutions. The engineers go for the numerical methods when there is some complex material properties and the boundary condition are found in the problem and this provides the solution which is acceptable.

V. FEM ANALYSIS

The process of predicting the deflection and the other effects on to the structure is basically termed as the Finite element analysis (FEA). This FEA basically divides the completer structure into small grids which together forms the complete structure. The FEA has the preset up information to write the governing equation into the stiffness matrix. Each element is divided into the simple shape such as rectangular or the square shape. The displacement at each node point is unknown for the each element. The stiffness matrix is assembled by the finite element program for the entire model. The stiffness matrix is generated at the each of the nodes and similarly each node is calculated.

$$\{F\}= \{K\} \{D\}$$

Where, {F} =Force vector
{K} =Stiffness matrix
{D}=displacement vector

VI. NACA

The book "History of Aerodynamics" written by John D. Anderson jr. gives the depth history of the NACA. This book was published in 1997 and was choose by many persons who love the history of aerodynamics. If we have any question about aeronautics, the satisfactory answer is written in the book. So with the help of these book lots of aircraft lovers get satisfied with the information and references provided into the book.

Example: NACA2412

– NACA2412

The first digit denotes the Maximum Camber line Height as in the percentage of the chord length. In this example, the 2 implies that the camber line will reach the maximum height which will be equals to 2% of the overall chord length. A value of twenty indicates that the air foil is asymmetrical in shape.

– NACA2412

The second digit denotes where will be the Maximum Camber line Height will as be chord wise as a percentage of chords length is in tenths. In this example, the number 4 implies that the camber line will reach its maximum height at the distance of 40% of the way back from the leading edge.

– NACA2412

As with the entire with o NACA airfoils, the last two digits combine together to denote how thick the air foil is as a percentage of chord length. In this example, our air foil will be 12% of the chord length thick.

VII. VIRTUAL WIND TUNNEL

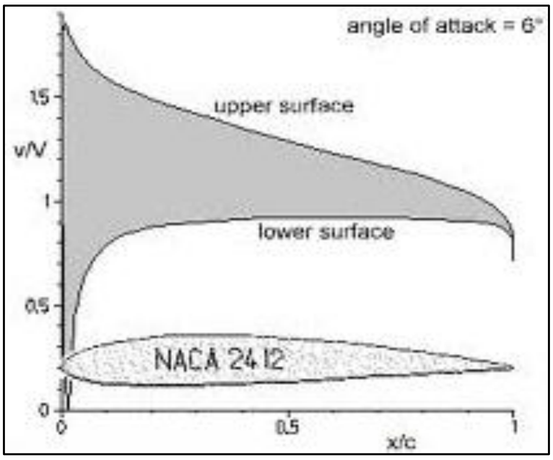


Fig. 7.1: Virtual wind tunnel result of the airfoil

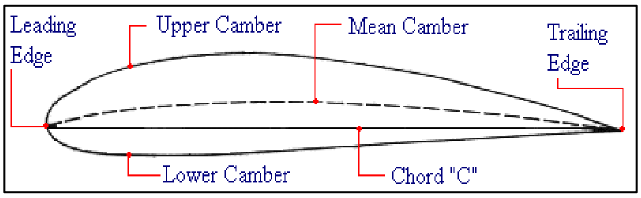
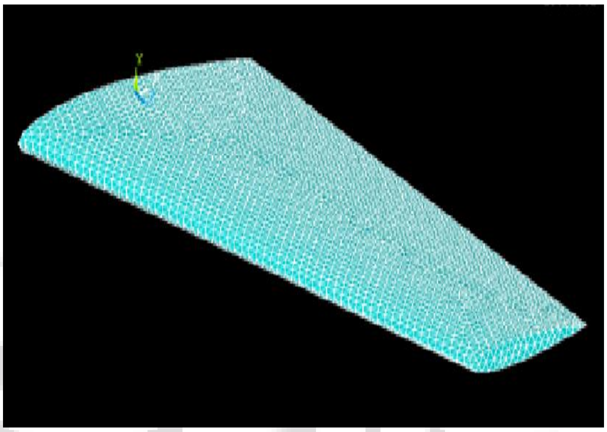


Fig. 7.2: Airfoil

VIII. RESULT & DISCUSSIONS ON THE TAPERD WING MADE OF BALSA WOOD

Now after designing the aircraft wing, we will the structural and vibration (model) analysis on ANSYS 12.1 software. Solid brick 10 node 187 element is used for structural analysis of solid wing and we used tetrahedral free mesh for analysis. First of all we were facing meshing problem then we used Blent Protrousion command while modeling then we got the perfect meshing.

A. Meshing



Now first we calculate the lift force using following formula at 10 different aircraft velocities:-

$$\text{Lift} = C_L \times 1/2\rho v^2 \times s$$

Where

C_L= Lift coefficient (angle of attack) = 1.6

S = the plan area (or wing area) of an airfoil = 0.14625 m^2

v = the TAS or an aircraft's velocity squared

ρ = the density of the air = 1.225 kg/m^2

B. Lift & Pressure at Various Velocities

S.No.	Velocity (V),m/s	Lift (N)	Pressure (N/mm^2)
1	20	57.33	3.92e-4
2	25	89.57	6.12e-4
3	30	128.99	8.81e-4
4	35	175.57	1.20e-3
5	40	229.32	1.56e-3
6	45	290.23	1.98e-3
7	50	358.31	2.45e-3
8	55	433.55	2.96e-3
9	60	515.97	3.52e-3
10	65	605.54	4.14e-3

Table 1: Lift & Pressure at Various Velocities

C. Results on ANSYS

1) Deflections & Stress:

At V = 20 m/s

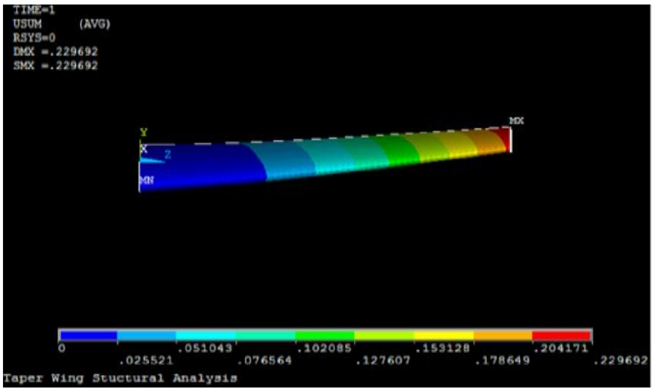


Fig. 8.3.1: Deflection

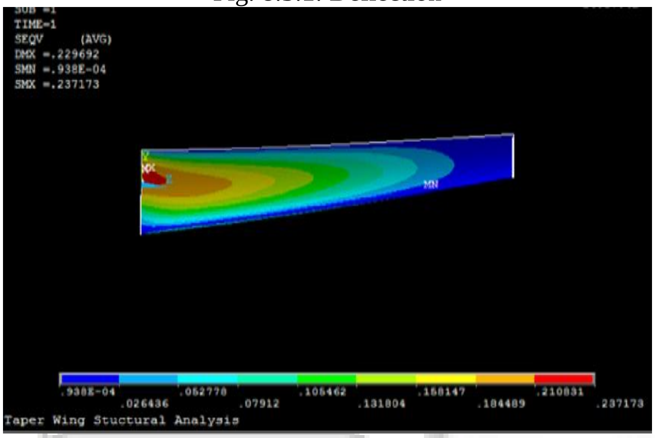


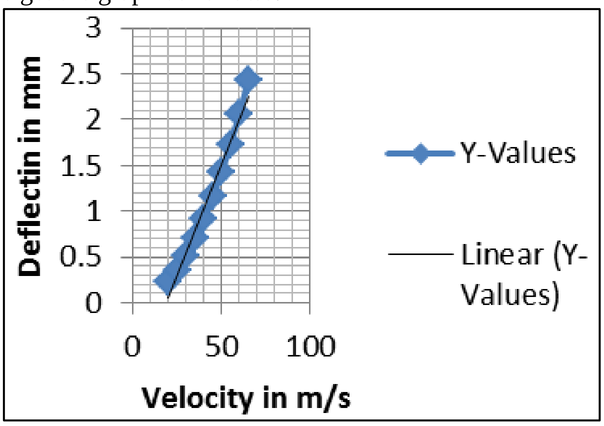
Fig. 8.3.2: Stress

2) *Deflections & Stresses at various velocities:*

S.No.	V (m/s)	Deflection (mm)	Stress (MPa)
1	20	0.2297	0.2371
2	25	0.3586	0.3703
3	30	0.5162	0.5330
4	35	0.7031	0.7260
5	40	0.914	0.9438
6	45	1.16	1.198
7	50	1.436	1.482
8	55	1.734	1.792
9	60	2.063	2.13
10	65	2.426	2.505

Table 2: Deflection v/s stress

We get the graph as follows:-



3) *Vibrational Analysis of Solid Tapered Wing of Balsa Wood:*

Solid brick 10 node 187 element is used for structural analysis of solid tapper wing and we used tetrahedral free mesh at the time of analysis. We apply the density of balsa wood on the ANSYS software it gives the deflection in frequency on infinite numbers but we calculated only 10 frequency.

Density of balsa wood = 0.17 e-9 ton/mm^3

– First step

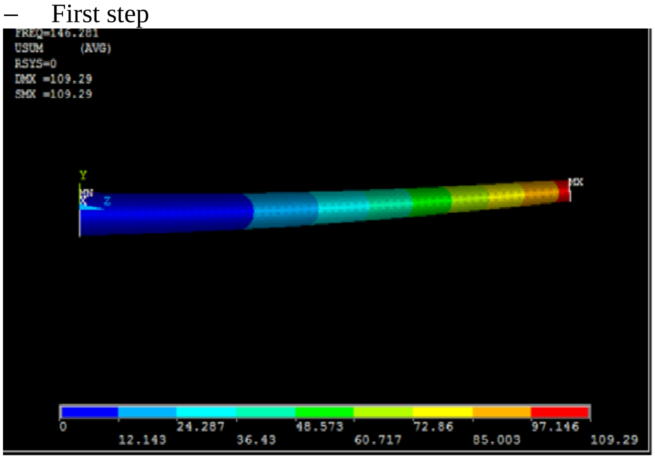


Fig 6.21 Mode shape 1

The maximum deflection = 109.29 mm

The natural frequency = 146.29 Hz

4) *After Ninth Step*

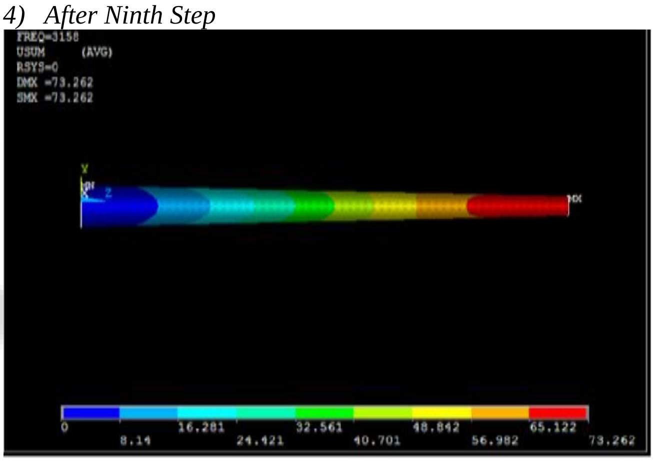
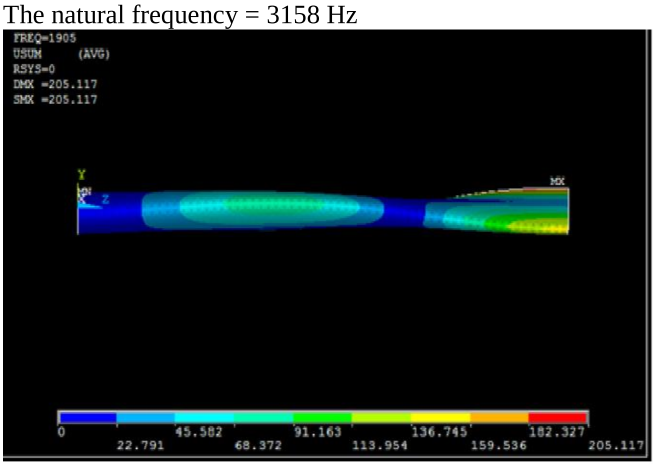


Fig. Mode shape 10

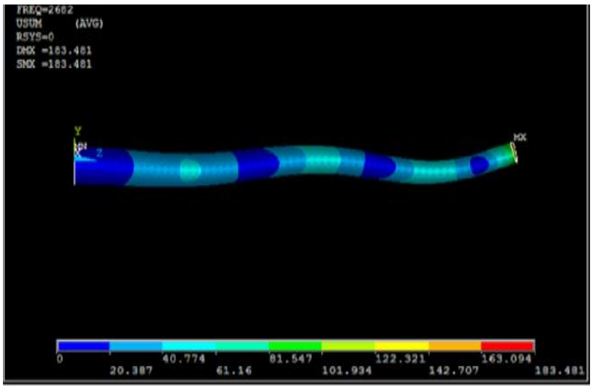
The maximum deflection = 73.262 mm

The natural frequency = 3158 Hz



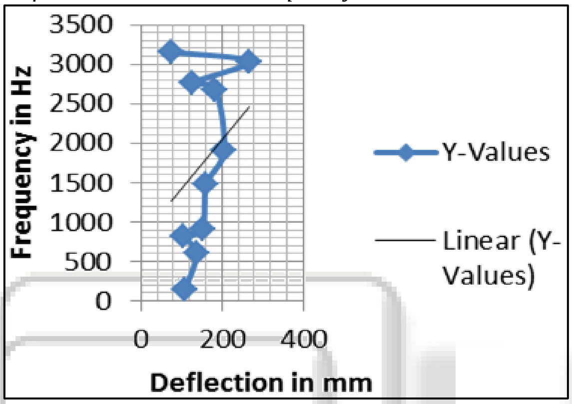
The maximum deflection = 205.117 mm

The natural frequency = 1905 Hz



The maximum deflection = 183.481 mm
The natural frequency = 2682 Hz
We get the following graph

5) Deflection Vs Natural Frequency:



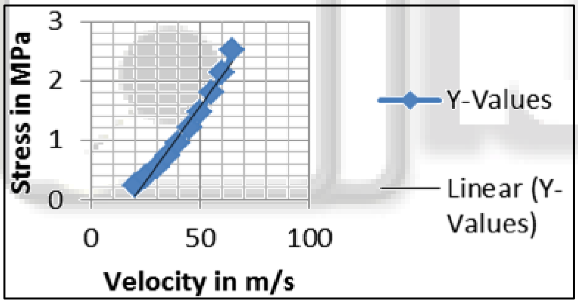


Fig. Velocity Vs Stress

IX. Conclusions

A productive result is found in this research that balsa wood designed model aircraft wing can be very effective for the further industry level manufacturing. As balsa wood has property that it lighter and stronger. Which is helps in the better and stable flight of the model aircraft.

Since Balsa Wood is having good stiffness property with low weight in comparison with the other material. Density of the balsa wood is 0.17 e-9 ton/mm^3, which very low and provide flexible nature to the material with low weight. Doing structural and vibrational analysis for the tapered wing we came on the validation that tapered wing is more effective than the plane wing.

After the analysis we came to the conclusion that after a limit the balsa wood manufactured aircraft wing moves towards the constant stress. So it is a better sign of success in the manufacturing for the balsa wood. When we had taken it for the vibrational analysis it also gave the satisfactory result that the frequency started to sudden reduce after a limit of velocity which causes the stress to the wing and can be seen from the above graph. The wing design is very much effective as NACA2412 airfoil has been used so, with the help of balsa wood, the wing is better to be used because in the obtained graph we can see that it is safer for the flight.

From the obtained result we can see that in the vibrational analysis deflection increase as the frequency increase but after a certain value the deflection start to sudden reduce, this is the main benefit which is taken by the balsa wood and after the analysis and validation we can say that balsa wood tapered wing will be much better for the manufacturing of the wing so that it can withstand in a balance mode at very high speed also.

When we have done the structural analysis we have seen the outstanding results for the structure of the wing, and found that balsa wood is structurally more reliable at high speed, because not only of its light weight but more structurally better in the weight strength ratio.

So it can be said that this type of wing span design with the help of balsa wood can be helpful for the designing of the amazing flying object, which we called the airplane.

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