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COMPUTATIONAL ANALYSIS OF NON-PNEUMATIC TYRES REFERING HONEYCOMB SHAPE FOR AIRCRAFT STRUCTURES

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Abstract

Non-pneumatic tyres are the tyres, which are not supported by air pressure. The non-pneumatic tyres overcome many disadvantages over conventional tyre like possibility of a catastrophic damage, required maintenance of proper internal air pressure and complex manufacturing procedure. Non-pneumatic tyres usually have higher rolling opposition and offer much less suspension than on the contrary shaped and sized pneumatic tyre. Additional troubles for (non-pneumatic) airless tyre contain dissipating the heat built-up that arises when they are driven. Non-pneumatic tyres are often packed with compacted polymers, relatively to air. Bearing in mind the non-pneumatic tyre structure, the spokes experience compression and tension under cyclic loading while the tyre rolls.

In the present scenario, the non-pneumatic tyres for the application of military trucks have been established and implementation has been accomplished. So, an attempt has been made to investigate the computational modelling and analysis of non-pneumatic tyres for aircraft structures by using suitable software's NX-8 & ANSYS for the purpose of low energy loss on rough surfaces, low contact pressure, low mass and low vertical stiffness. The total deformation of Honeycomb structure is very marginal when compared to diameter of non-pneumatic tyre. Hence honeycomb structure can be recommended for non-pneumatic tyre for aircraft structure. Modal analysis has been carried out to determine the natural frequency and corresponding initial modes.

Keywords: Tyre, Non-pneumatic tyre, honeycomb structure, NX-8, ANSYS

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1. Introduction

For more than 100 years, vehicles have been rolling along on cushions of air encased in rubber as shown in fig. 1. Michelin and Bridgestone have started experimenting with design for non-pneumatic tyres, creating a new non-pneumatic design for tyres has more positive implications than one might think [1]. There are advantages viz., low vertical stiffness, low contact pressure, low energy loss on rough surfaces, and low mass. Having anon-pneumatic tyre means there is no possibility of a blowout, which, in turn, means the number of accidents will reduce and cut significantly. Even for situations in the military shown in fig. 2, utilizing non-pneumatic tyres has a great positive impact on safety. Tyres are the weak point in military vehicles and are often targeted with explosives.

Fig. 1. Pneumatic Tyre of Aircraft

Non-pneumatic tyres can be made with different spoke tension, allowing for different handling characteristics. The lateral stiffness of the tyre is also adjustable. The non-pneumatic tyre is a single unit replacing the pneumatic tyre, wheel and valve assembly. It replaces all the components of a typical radial tyre and is comprised of a rigid hub, connected to a shear band by means of flexible, deformable polyurethane spokes and a tread band, all functioning as a single unit. The tweel, a kind of non-pneumatictyre, though finds its generic application in military and earth moving applications due to its flat proof design can also render the pneumatic tyre obsolete in Aircraft wheels.

2. Literature Review

Yazid et al. [1] examined three dissimilar structures of the tweel, resistant technologies, and NPT by seeking yielding spoke structures. They conducted the quasi-static, two-dimensional analysis on contact pressure, vertical tyre stiffness and stress which are affected by spoke structures and shear band by creating two NPTs, a tyre with a composite ring and another without composite ring. The results depicted that shape and size of spokes has effect on tyre behavior and the shear layer reduces the impact of the deformed spokes shape in contact pressure distribution.

Bras et al. [2] discussed about the ecological effect of the tweel tyre and its lifecycle from assembling, through use and transfer. Since the tweel tyre is as of now still in the examination stage and is most certainly not made and utilized on a vast scale, there are instabilities as for end-of-life situations and rolling resistance evaluates that will influence the Life Cycle Assessment (LCA). In any case, some preparatory finishes of the tweel tyre's natural execution in contrast with a traditional spiral tyre can be drawn.

Ramachandran et al. [3, 4] improved the analysis procedure with an improved initial\start-up procedure for steady rolling. Major findings from this work depicted the effect of edge scalloping on the three-dimension spoke model. By removing material from the edges of the spokes through scalloping, vibration amplitude has been reduced substantially. An optimal amount of edge scalloping has been determined.

3. Problem Definition

Non-pneumatic tyres usually have higher rolling opposition and offer much less suspension than on the contrary shaped and sized pneumatic tyre. Additional troubles for airless tyre contain dissipating the heat built-up that arises when they are driven. Non-pneumatic tyres are often packed with compacted polymers, relatively to air. Bearing in mind the non-pneumatic tyre structure, the spokes experience compression and tension under cyclic loading while the tyre rolls. In this project work, the non-pneumatic tyrehas been studied with honeycomb and V-structure spokes. Non- pneumatic tyres are the tyres that are not supported by air pressure [8]. They overcome many disadvantages over conventional tyre like possibility of a catastrophic damage, required maintenance of proper internal air pressure and complex manufacturing procedure.

Therefore, it is essential to reduce the localized stress of spokes i.e., the spokes must be fatigue resistance. In this project, non-pneumatic of honeycomb structure modelling and analysis and analysing stress, deformation, frequency and mode shapes.

4. Objectives

- Modelling of the non-pneumatic tyres for different structures viz., Honeycomb structure using Uni-Graphics (NX-8.0)
- Determination of linear stresses and deformation using static structural analysis.
- Determination of frequency and mode shapes using modal analysis.

5. Methodology

- Solid Modelling of Honeycomb Structure for Non-Pneumatic Tyre with the Help of Uni-Graphics
- Study of Non-Pneumatic Tyre
- Analysing the Stresses and Deformations
- Analysing Frequency and Mode Shapes

6. Material Properties of Non-Pneumatic Tyre

Table 1: Material Properties

Part	Hub	Spokes	Outer Ring	Shear Band
For Pneumatic Tyre	Yes	No (AIR)	No	No
For Non-Pneumatic Tyre	Yes	Yes	Yes	Yes
Material	Al 7075	Polyurethane	AISI 4140	Synthetic Rubber
Yield Stress (MPa)	503	145	480	38.2
Young's Modulus(MPa)	75000	35	210000	14
Poisson's Ratio	0.33	0.48	0.3	0.48
Density (Kg/m^3)	2180	1210	7810	1050

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7. Computational Analysis on Honeycomb Structure

7.1 Introduction to Honeycomb Structure

The modelling of Honeycomb structure using a software Uni-Graphics (NX-8.0) with required parameters comprises the aspects namely meshing pattern, use of boundary conditions i.e., rotational velocity and force by employing linear static analysis. Also, modal analysis to explore the distribution in frequency has been exploded.

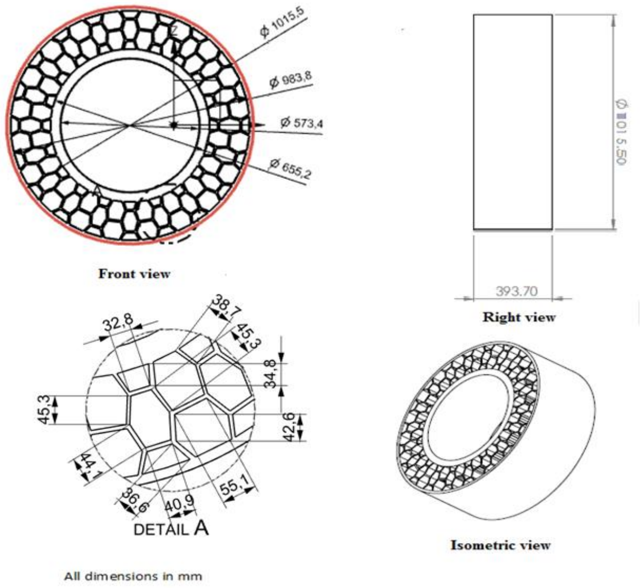

Fig. 3. Views of Honeycomb Structure

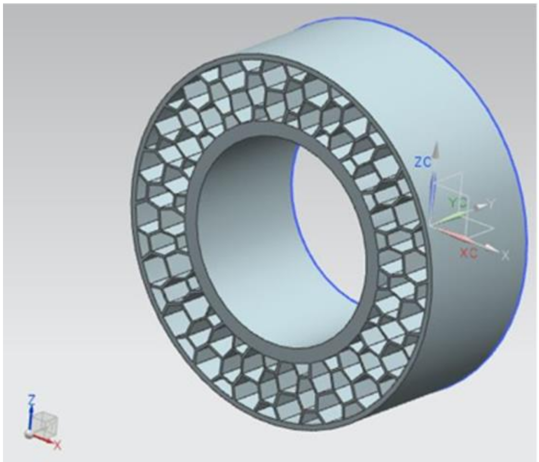

Fig. 4. Final Model of Honeycomb Structure

Statistics	
Nodes	52479
Elements	8011
Mesh Metric	None

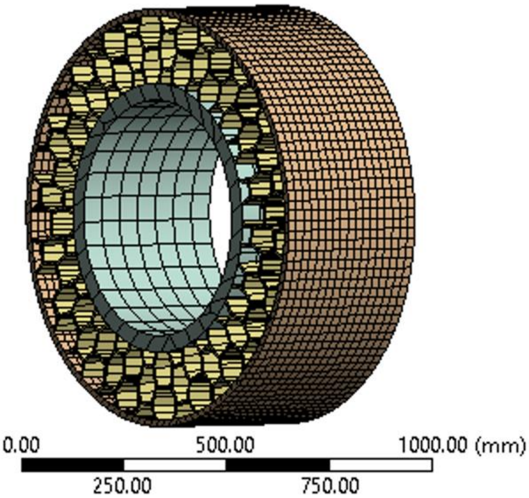

Fig. 5. Meshed Model of Honeycomb Tyre

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Fig. 5 depicts the meshed model of honeycomb tyre. The elements used for the meshing is Hex-dominant three-dimensional element (Triangular surface mesher). The mesh contains a combination of tetra and pyramid cells with majority of cell being of hex type. Hex-dominant meshing reduced element count and increases the number of nodes.

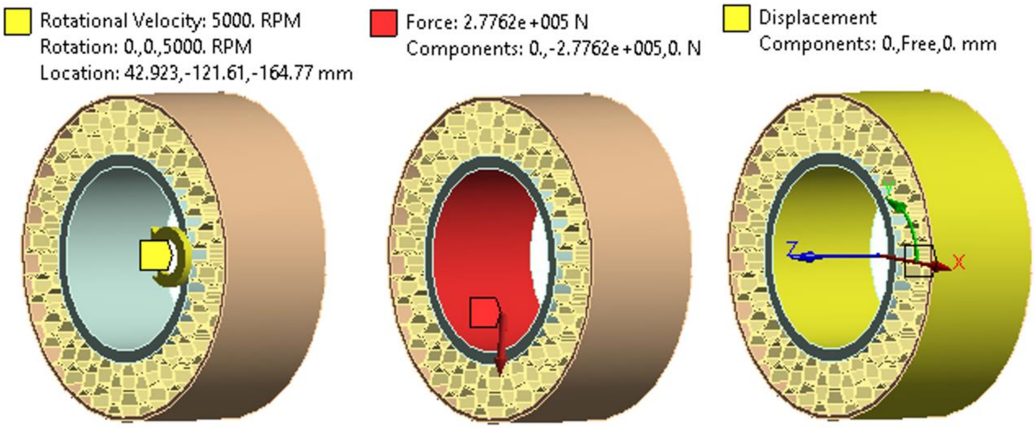

Fig. 6. Boundary Conditions for Honeycomb Tyre

The force of 277623 N is applied in the negative y-direction at the inner surface of the wheel and Rotational velocity of 5000 rpm is applied in z-direction depict in fig. 6. The complete table has shown in appendix-I and x-component is left free for deformation since y and z directions does not depict much deformation.

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7.2 Linear Static Analysis

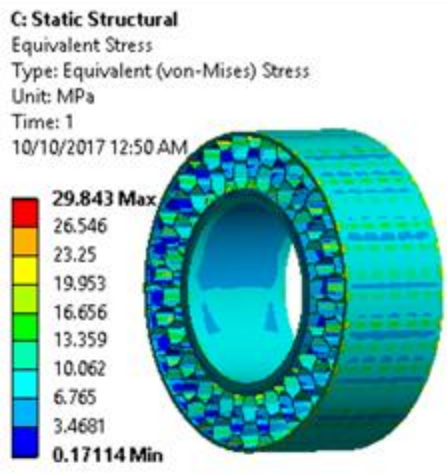

Fig. 7. Von-Mises Stress

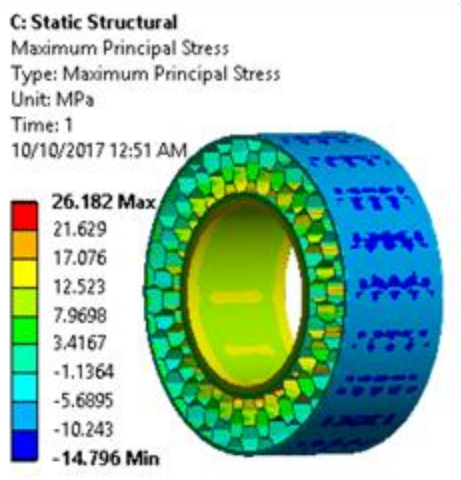

Fig. 8.Maximum Principal Stress

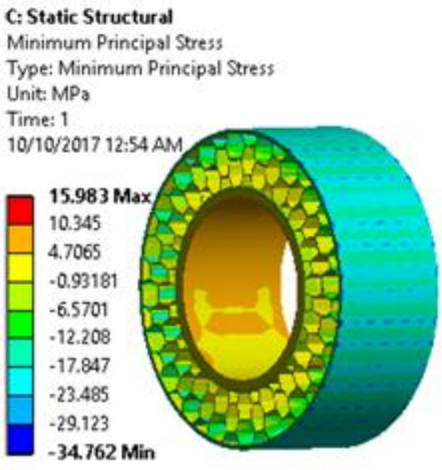

Fig.9. Minimum Principal Stress

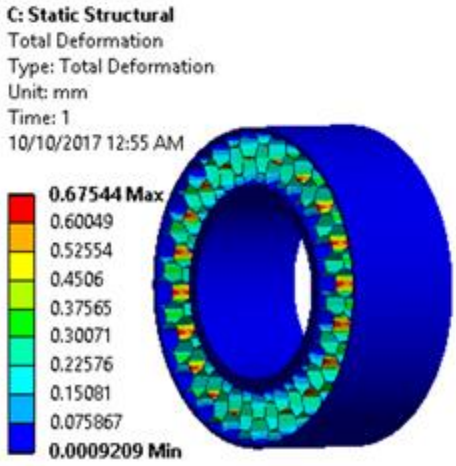

Fig. 10. Total Deformation

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Table 2. Static Analysis of Honeycomb Structure

Static Analysis	Honeycomb Structure
Equivalent Stress	29.84 MPa
Maximum Principal Stress	26.18 MPa
Minimum Principal Stress	15.98 MPa
Total Deformation	0.67 mm

Table 1 depicts the materials properties. From table 2, linear static structural analysis has been carried out to estimate the maximum stress and deformation of non-pneumatic tire of aircraft structure. It is found that ultimate stress of 29.84 MPa, total deformation of 0.67 mm is obtained along the honeycomb structure of non-pneumatic tyre. The stresses that are obtained from the static analysis of non-pneumatic tyre are low depending on the yield stress of material which is considered for the pertinent boundary conditions. The total deformation 0.67 mm obtained from the static analysis of honeycomb structure non-pneumatic tyre is very marginal when compared to diameter of the non-pneumatic tyre. It regains its original shape because of the flexibility property of considers material. It can be observed from fig. 7, 8 & 9, the value of stresses is seem to be endurable for aircraft structures by the use of non-pneumatic tyres. Also, from fig. 10, the magnitude of total deformation achieved is favourable for aircraft structures by employing honeycomb structure.

7.3 Modal Analysis

Modal Analysis is performed to evaluate the mode shapes with corresponding frequency of the non-pneumatic tyre. In this project, it has been conducted modal analysis to determine different natural frequency, total deformation and mode shapes. Mode shapes with natural frequency

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occurs for the applied static load of 277623 N and 5000 rpm rotation applied in the y & z-directions.

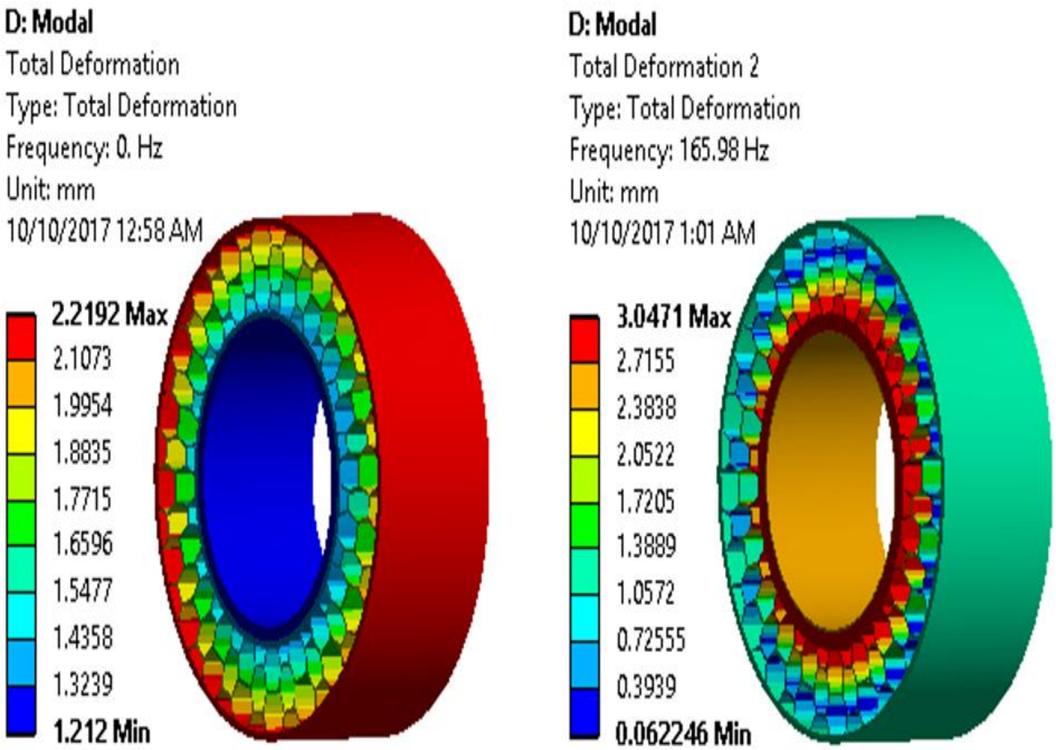

Fig 11. First and Second Mode of Deformation

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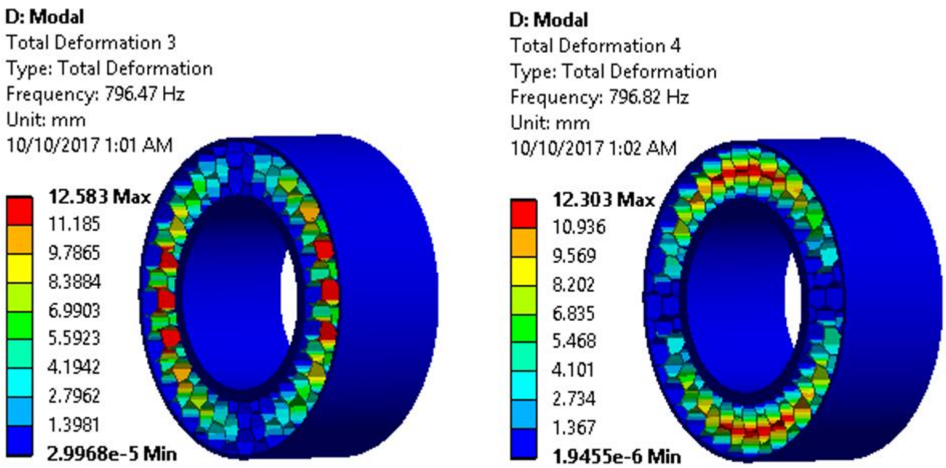

Fig 12. Third and Fourth Mode of Deformation

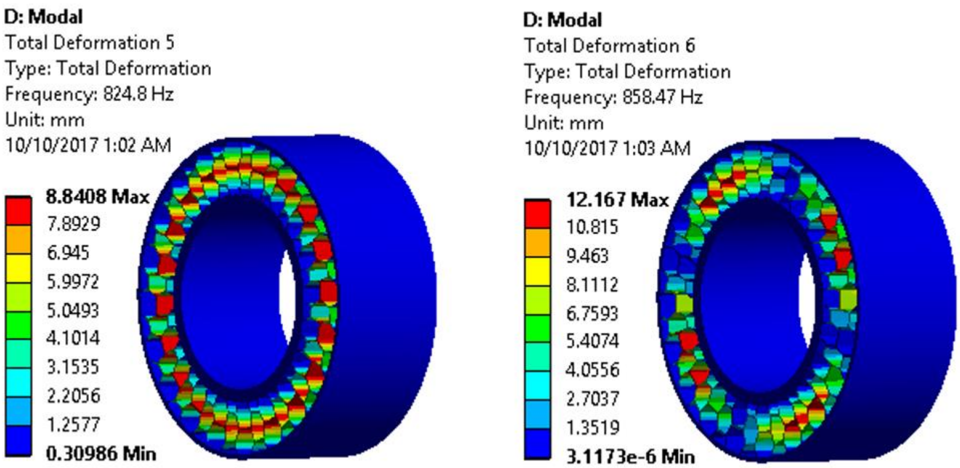

Fig 13. Fifth and Sixth Mode of Deformation

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Table 3. Results of Frequency and Deformation w.r.t Modes of Honeycomb Structure

Modes	Frequency (Hz)	Deformation (mm)
1	0	2.219
2	165.98	3.047
3	796.47	12.583
4	796.82	12.303
5	824.80	8.840
6	858.47	12.167

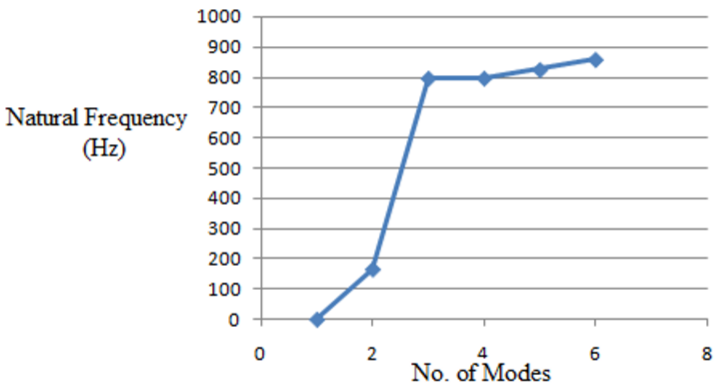

Fig. 14. Variation of Natural Frequency with Modes

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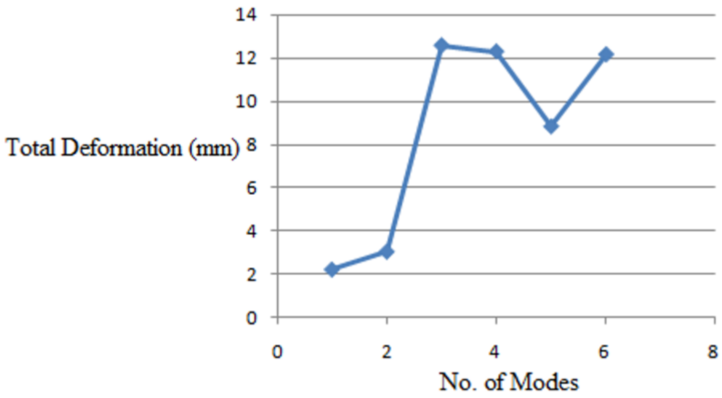

Fig 15. Variation of Total Deformation with Modes

From table 3.2, modal analysis has been carried out to estimate the natural frequency, deformation, and corresponding modes of non-pneumatic tyre favourable for aircraft. From table 3.2, modes 1 & 2 are in in-plane loading i.e., deformation occurs mainly due to self-weight and modes 3 to 6 are in out-plane loading i.e., deformation occurs mainly due to external force but modes 2 to 3 is mixed mode loading i.e., deformation occurs due to combination of in-plane and out-plane loading. Hence from modes 2 to 3 there has been a radical increase in both frequency and deformation with respect to modes of honeycomb structure non-pneumatic tyre shown in fig. 14 and 15. In the fig. 15, it can be observed that, due to the combined effect of in-plane and out-plane loading conditions, the total deformation with respect to number of modes vary inconsistently.

8. Conclusions

In this project work, computational modelling and analysis for non-pneumatic tyres beneficial for aircraft structures, by the use of honeycomb structure have been accomplished. Linear static analysis has been employed to explore stress and total deformation for honeycomb structure. Also, modal analysis has been carried out to determine natural frequency. Based on the above, the following are the major conclusions that have been drawn:

1. Linear static structural analysis has been carried out to estimate the maximum stress and deformation of non-pneumatic tyre of aircraft structures. It is found that, ultimate stress of 29.84

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MPa, total deformation of 0.67 mm is obtained along the honeycomb structure of non-pneumatic tyre.

2. The stresses that are obtained from the static analysis of honeycomb structure non-pneumatic tyre are low, depending on the yield stress of material which is considered for the pertinent boundary conditions

3. The total deformation of 0.67 mm obtained from the static analysis of honeycomb structure non-pneumatic tyre is marginal when compared to the diameter of the non-pneumatic tyre. It regains its original shape because of the flexibility property of considers material.

4. Modal analysis has been carried out to estimate the natural frequency, deformation, and corresponding modes of non-pneumatic tyre favourable for aircraft. Modes 1 & 2 are in-plane and modes 3 to 6 are in out-plane but modes2 to 3 is mixed mode loading. Hence from modes 2 to 3, there is a radical increase in both frequency and deformation with respect to modes of honeycomb structure non-pneumatic tyre.

9. Scope for Future Work

- The non-pneumatic tyre based on hexagonal honeycomb structure can be used to replace a conventional pneumatic tyre. Moreover, hexagonal honeycombs can simply be modified to have desired in-plane properties by varying cell angle, the wall length, and wall thickness.
- Research and Development sectors should take the initiative in arranging for comprehensive experimentation facility, with reference to construction of aircrafts.
- Experimental and numerical approaches shall be adopted to accomplish validation.

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