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Research paper

Dynamic Characteristic based Structural Optimisation of a Typical UAV Wing

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Abstract

Paper presents the modal analysis and rib design part of the project for weight optimization of wing for flutter. Resonance and flutter are important vibration problems. The ribs should be placed such that flutter speed is outside the working speed range. If the flutter speed is well above working speed range, weight optimization can be done to find a balance between the two.

Keywords— Modal analysis, Wing, ANSYS, Ribs

1. Introduction

Resonance is a major vibration problem occurring in most of the structures which can contribute to the failing of the structure. Resonance occurs when the system is excited at its natural frequency. At resonance large amplitudes and violent oscillations may occur.

In order to find the natural frequencies of a system, modal analysis is used. Mode is a structural property characterized by a modal frequency and mode shape. Modes can be bending or torsion in nature. Coupling of modes may also occur in real time conditions. Modal analysis is useful in structural health monitoring.

A part of the project for optimizing the weight of a wing for flutter is presented in this paper. Flutter is a very important vibration phenomenon in wings or even structures exposed to fluid flow or when there is an interaction between the structure and fluid. At flutter speed, the structure undergoes sustained oscillations and above it the structure starts extracting energy from fluid leading to violent oscillations and ultimately failure of the structure. The modal analysis can be used in determination of flutter. The flutter speed can be calculated for the first bending and torsion modes and optimized for the same.

2. Model of Wing

The model of the wing is modeled using CATIA V5. Three models are considered. The airfoil selected is NACA 2415 with root chord of 2880mm and tip chord of 600mm. The sweep angle and tilt of tip airfoil section is 34 degree. Overall span of the wing is 2037mm. Fig.1 shows model of wing without ribs. Rib positions are decided based on trial and error taking in to consideration the maximum stress and deformation locations from analysis of wing without ribs and local mode excitations.

Model A has seven cross ribs of 5mm thickness are constructed in stream wise direction at 300mm, 350mm, 600mm, 900mm, 1200mm, 1500mm and 1800mm from the root section. Four spars of width 5mm and height 5mm cross section is constructed at 587mm, 1140 mm and 1690mm and 2251.01mm from trailing edge of root cross section. 10 holes of diameter 16mm and equally spaced at 250mm are made at the top and bottom surface of the wing at 100mm offset from root. Stiffeners equally spaced at 250mm, 300mm, 350mm, 400mm, 450mm, 475 and 500mm starting from tip end are modeled in the cross ribs. Model B has 6 cross ribs at locations 300mm, 600mm, 900mm, 1200mm, 1500mm and 1800mm and 3 spars at 587mm, 1140mm and 1690mm. Model C has three cross ribs at 600, 1200 and 1500mm with three spars. Model D has two cross ribs at 900 and 1500mm with three spars.

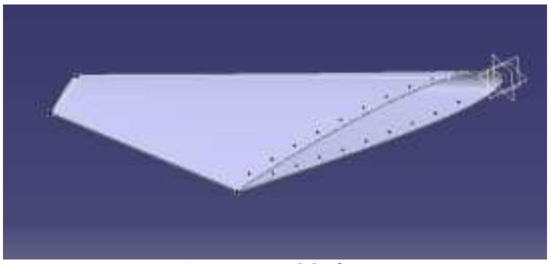


Figure.1: Model of wing

3. Ansys Analysis

For analysis, the holes are filled using fill command so as to simulate a bolted joint. Analysis is carried out for a speed of 60 Kmph. The bottom faces of the bolt are fixed. A dynamic pressure load of 200 Pa is applied in z-direction on the lower face of the wing. A bonded contact is formed between the ribs and inner faces of the wing. A bonded contact is also made between the bolt and holes. Material used for the wing surface and ribs is aluminum alloy and for bolt structural steel is used. All analysis is carried out on clean wing surface without control surfaces. Material properties are given in Table 1. Mesh properties are shown in Table 2.

Table 1:. Material Properties

Material	Structural Steel
Density	7850 kg/m3
Young's Modulus	2e11 Pa
Poisson's Ratio	0.3
Tensile and Compressive Yield strength	2.5e8 Pa
Tensile Ultimate strength	4.6e8 Pa
Material	Aluminium
Density	2770 kg/m3
Young's Modulus	7.1e10 Pa
Poisson's Ratio	0.33
Tensile and Compressive Yield strength	2.8e8 Pa
Tensile Ultimate strength	3.1e8 Pa

Table 2:. Mesh Properties

Physics	Mechanical
Size Function	Adaptive
Relevance Centre	Medium
Element Size	Default
Transition	Fast
Span Angle Centre	Medium
Smoothing	High

3.1 Static Structural

The total deformation of the wing without ribs is 1.67 mm and maximum stress is 156.14 MPa. The total deformation of model A is 0.35 mm and maximum stress is 67.09 MPa. The maximum stress occurs in the bolt. For model B the maximum deformation is about 0.35 mm and maximum stress is about 103.51 MPa. Model C gives a total deformation of 0.36 mm and maximum stress of 105.92 MPa. Model D has total deformation of 0.37 mm and maximum stress of 106.54 MPa.

3.2 Modal Analysis

Modal analysis is carried out for all the models. Modal frequencies for wing without ribs are shown in Table 3. The frequencies for model A, B, C, D are given in Table 4, 5, 6 and 7 respectively and mode shapes are shown in Fig.2, Fig.3, Fig.4 and Fig.5. It can be seen that without ribs all modes are shell modes. Hence, stiffness of the structure has to be increased by ribbing to eliminate shell modes.

Table 3:. Modal frequencies for wing without ribs

Mode	Frequency (Hz)	Type
1	33.82	Local
2	47.906	Local
3	52.069	Local
4	69.53	Local
5	77.101	Local
6	94.456	Local

Table 4:. Modal frequencies for model A

Mode	Frequency (Hz)	Type
1	47.24	Bending (1st)
2	70.57	Bending (2nd + Local
3	114.24	Torsion (1st)
4	122.27	Bending (3rd)
5	142.84	Torsion (2nd) + Local
6	168.59	Torsion (3rd)

Table 5:. Modal frequencies for model B

Mode	Frequency (Hz)	Type
1	45.854	Bending (1st)
2	59.589	Bending (2nd) + Local
3	94.251	Torsion (1st) + Local
4	98.47	Bending (3rd) + Local
5	101.86	Torsion (2nd) + Local
6	105.38	Torsion (3rd) + Local

Table 6:. Modal frequencies for model C

Mode	Frequency (Hz)	Type
1	45.235	Bending (1st)
2	59.229	Bending (2nd) + Local
3	96.859	Torsion (1st) + Local
4	113.26	Bending (4th) + Local
5	119.96	Torsion (2nd) + Local
6	144.29	Torsion (3rd) + Local

Table 7:. Modal frequencies for model D

Mode	Frequency (Hz)	Type
1	45.739	Bending (1st)
2	62.135	Bending (2nd) + Local
3	94.672	Torsion (1st) + Local
4	112.15	Bending (3rd) + Local
5	122.77	Torsion (2nd) + Local
6	135.47	Torsion (3rd) + Local

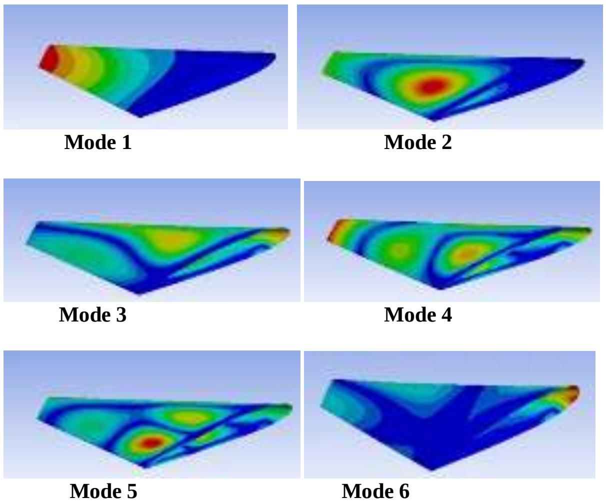


Figure.2: Mode shapes of model A

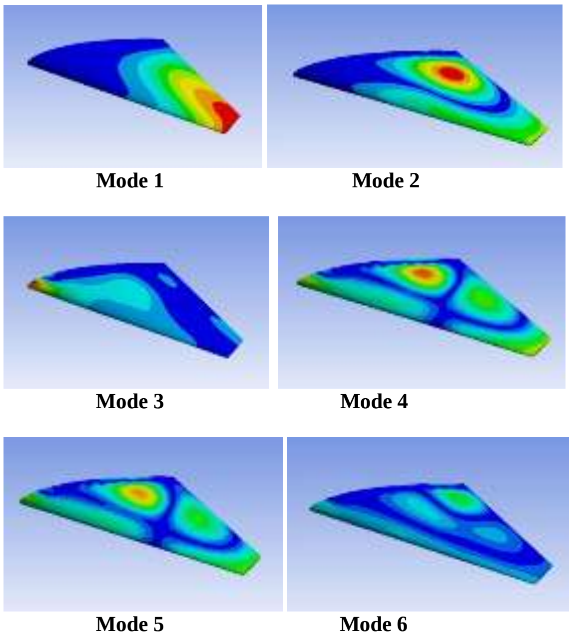
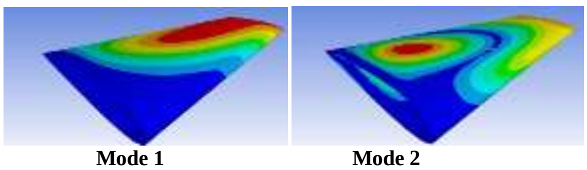


Figure.3: Mode shapes of model B.



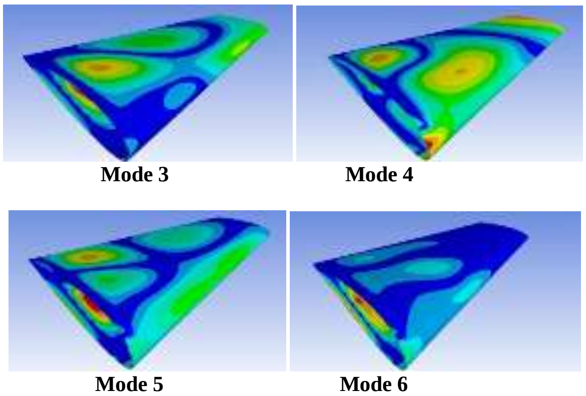


Figure.4: Mode shapes for model C.

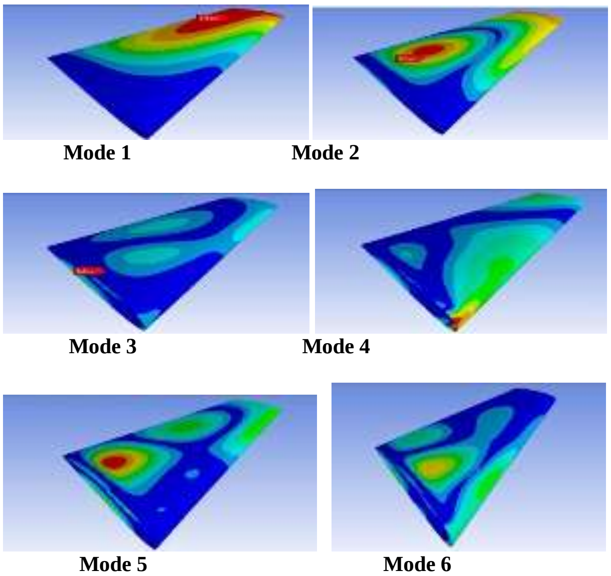


Figure.5: Mode shapes for model D.

3.3 Harmonic Analysis

Harmonic analysis is carried out on all models to find the stresses and displacements produced when ‘4g’ of base excitation is applied at the fixed supports to simulate the excitations due to fuselage. For each mode the dynamic stresses generated are shown in Table. 8, 9, 10, 11.

Table 8.: Dynamic stress (Model A)

Mode	**Stress (N/mm2)**
1	216.15
2	108.49
3	159.54
4	240.38
5	203.53
6	83.864

Table 9. Dynamic stress (Model B)

Mode	Stress (N/mm2)
1	213.64
2	316.97
3	927.48
4	1592.3
5	697.09
6	496.02

Table 10:. Dynamic stress (Model C)

Mode	**Stress (N/mm2)**
1	331.69
2	231.68
3	331.2
4	324.07
5	653.03
6	114.07

Table 11:. Dynamic stress (Model D)

Mode	**Stress (N/mm2)**
1	303.55
2	977.91
3	324.94
4	364.1
5	731.88
6	392.75

4. Conclusion

It can be seen that the local modes are excited at almost all the frequencies and occur along with the bending or torsion modes for models B, C and D, which means that the spacing between the ribs is large and the structure does not have sufficient stiffness. The corresponding dynamic stresses for each mode in case of these models are also very high as can be seen from Table. 9, 10, 11. For model A, local modes occur only at two frequencies, i.e., along with second bending and torsion modes. Only the first bending and torsion modes are considered for flutter analysis. The dynamic stress for model A for each mode also less compared to other models and well within the yield strength of aluminum and structural steel used in the model for analysis. The static stress and deformation are also within acceptable values. Hence, Model A is selected for further analysis. Flutter speed will be calculated for this model.

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