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A numerical study to investigate the modal analyses of cracked airplane wing (NACA2415)

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One of the major concerns for the structural failure of an airplane wing is initiation of fatigue crack and its propagation from the wing root region. The modal analyses is one of the important tool used to determine the dynamics behaviour of airplane wing structure including natural frequencies and modes shapes. In the present study, an attempt has been made to perform the modal analyses of aircraft wing structure without cracked airplane wing structure and with cracked airplane wing structure (NACA2415). The effect of the crack length, depth of the crack and location of the crack on the natural frequency is also investigated. The results of modal analyses for uncrack wing structure are compared with the results reported in the literature. The numerical results show that the natural frequency is affected by the presence of crack.

***Keywords*:** Cracked Airplane Wing Structure, Finite Element Analysis, Triangular Crack

1. Introduction

The necessary lift to make an airplane fly can be provided by the wings of the airplane. The structure of the wing consists of outer skin, spar webs, and ribs. The spar webs are the most important load carrying member of the wing structure which is extended from fuselage to the tip of the wing structure[1]. The most of the load of the wing structure is carried by the spars so that the spars are designed to have high bending strength[1].

It is important to study the dynamic behaviour of the aircraft wing structures determined by the modal analyses. By using the modal analyses, one can improve the overall performance of the system in certain operating conditions. It helps to find the reasons of undesired vibrations that may cause damage to the integrated system components resulting in failure of any structure.

Carrera et al. has investigated refined and component wise models, comparison of result done on commercial finite element software. The author performed modal analyses on the two different aircraft wing structures for different degree of freedom[1]. Ostachowicz et al. has investigated the effect of the two open cracks present on the single side or double side of the cantilever beam, on the natural frequency of the cantilever beam[2]. Khalkar et al. has investigated the effect of rectangular shape and V-shape edge cracks on the natural frequency and static deflection of the spring steel cantilever beam[3]. Wang et al. has investigated a simple support point at which if we applied the minimum stiffness support that increases the natural frequency of the beam for the different boundary condition[4]. Sawant and Chauchan et al. has performed modal analyses on healthy beam and cracked beam and investigate the effect of crack on natural frequency at different location and different crack depth[5]. Satpute et al. has investigated behaviour of healthy and cracked beam and conclude the natural frequency to detect the crack in cantilever shaft[6]. Taylan Das et al. studied numerical and experimental modal analyses of curved composite wing with cracks of different depths and different location and different boundary condition like fixed-fixed and fixed-free[7].

In the present study, a numerical modal analysis is carried out to investigate the effect of crack length, depth and crack location on the aircraft wing structure. Both uncracked and cracked aircraft wing structure are modelled and analysis is performed using finite element based software platform ANSYS. The numerical results are validated with the results reported in literature.

2. Modelling of Airplane Wing (NACA2415)

The modelling of the aircraft wing is done corresponding to the geometrical dimensions reported in literature [1]. The cross-section of the wing with dimensions is illustrated in Fig. 1. The NACA2415 airfoil is used to create the wing with two spar webs and four spar caps are add-on. The chord length (C) of the airfoil is 1 mt. The length (L) along the span direction is equal to 6 mt. The thickness of the spar webs of the aircraft wing is 5×10^{-3} mt. The dimensions of the spars flanges are illustrated in Figure 1. The isotropic material is used for the whole structure and the material properties are listed in Table 1.

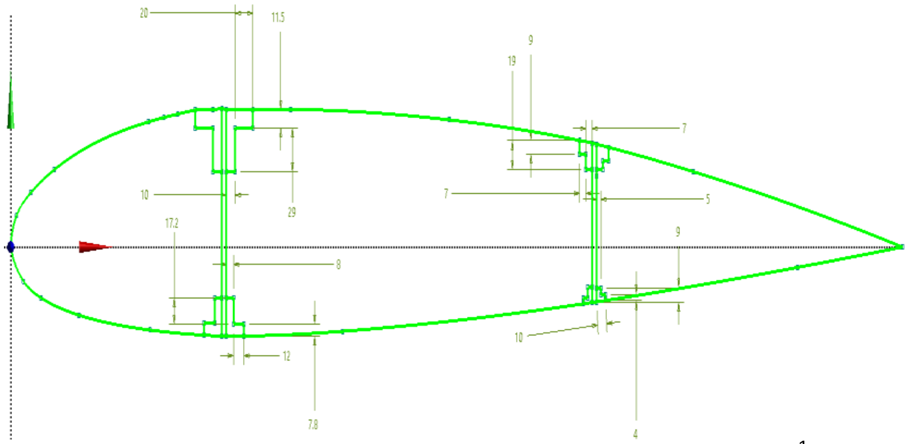

Fig. 1. Cross-section of the wing with dimensions (mm)[1]

Table. 1. Material properties of the aircraft wings structure[1]

Material Properties	**Value**
Modulus of Elasticity (E)	75 GPa
Bulk Modulus (K)	73.529 GPa
Modulus of Rigidity (G)	28.195 GPa
Density (ρ)	2700 kg/m^3
Poisson's Ratio (υ)	0.33

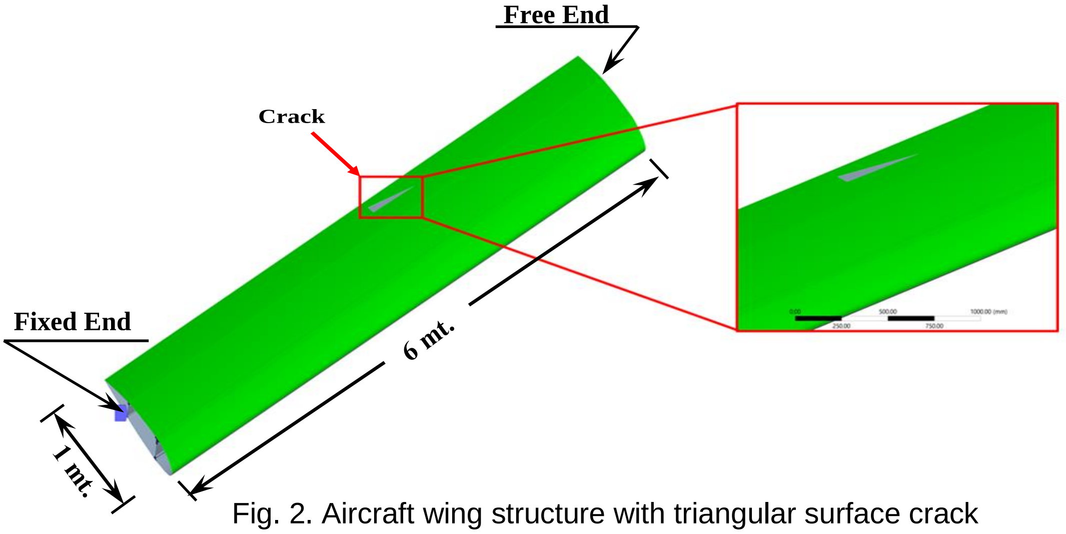

Fig. 2. Aircraft wing structure with triangular surface crack

The aircraft wing structure was assigned the material properties same as listed in Table 1. The left face of the wing structure is fixed in order to maintain the realistic cantilever boundary conditions while the rest of the structure is kept free. At fixed edge, all the degree of freedoms are fixed. It is to be noted that the geometric properties, material properties and boundary conditions are kept same for both cracked and uncracked aircraft wing structure.

3. Numerical Analysis based on FEM

Thereafter, the finite element analysis is performed on both cracked and uncracked aircraft wing structure using commercially available software package ANSYS vs 19.0. For the discretization of the structure, four node tetrahedral element is used. The uncracked aircraft wing structure is having 83700 no. of element while the cracked aircraft wing structure is having 77169 no. of elements. Figure 6 illustrates the discretized model of both cracked and uncracked aircraft wing structure.

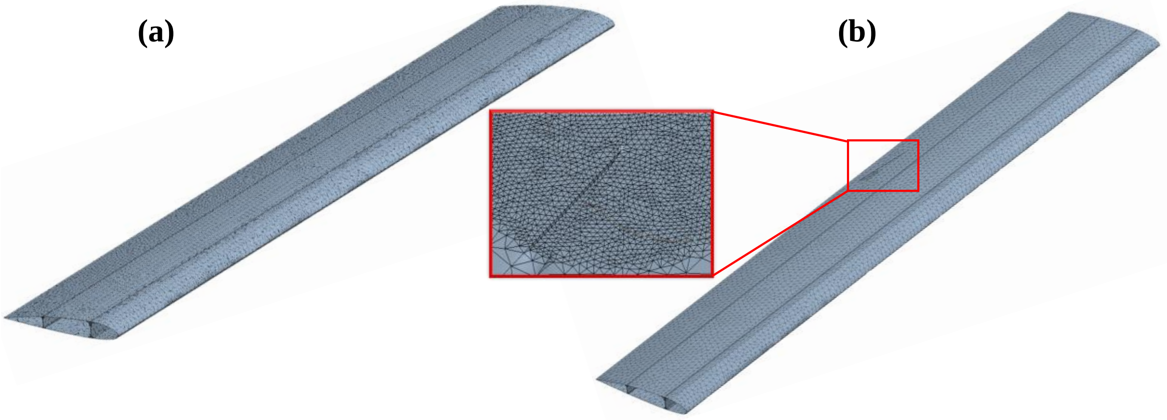

Fig. 3. Discretized model of aircraft wing structure: (a) Uncracked and (b) Cracked

4. Results and Discussion

In order to check the reliability, firstly a validation study is performed and the results of the present analysis are compared with the results reported by Carrera et al.[1]. The same geometric properties, material properties and boundary conditions are adopted. The validation results of the present study with Carrera et al.[1] are listed in Table 2. The results of present study are in good agreement with reported results.

Table. 2. Comparison of frequency values obtained from Present study and Carrera et al.[1]

Mode Shapes	Carrera et al.[1]	Present Study	Error (%)
I Bending^x	4.21	4.2814	1.69
I Bending^z	21.69	21.632	0.26
II Bending^x	24.78	26.083	5.25
Torsion	29.18	30.39	4.14
III Bending^x	56.12	59.97	6.86

Thereafter, an investigation on the effect of natural frequencies and mode shape are carried out by introducing triangular crack at a location 3269.78 mm away from the fixed end keeping constant crack length of 0.507mt and the crack depth is varied as 1.8mm, 1.5mm, 1.0mm, 0.5mm and 0.2mm respectively. It is observed from the numerical results that the frequencies keep of aircraft wing structure keeps on decreasing with increase in the depth of the crack and listed in Table 3. Presence of crack may reduce the local stiffness of the airplane wing structure at crack location which is calculated from the stiffness matrix. Moment of Inertia of the airplane wing is reduced in presence of crack and further reduced with increasing of crack depth results in reduced natural frequency.

Another investigation on frequency is carried out with triangular crack at same location with different crack length such as 0.6m, 0.65m, 0.7m, 0.73m and constant depth of crack 1.8mm. The results show that first natural frequency is a function of crack length. First natural frequency is decreasing with increasing crack length.

Table. 3. Effect of depth of crack on natural frequency of cracked aircraft wing structure

Depth of crack (mm)	Crack length (mm)	Frequency, f_n (Hz)		
		First	Second	Third
0	0	4.2814	21.632	26.083
0.2	507	4.2757	21.068	26.044
0.5	507	4.2628	20.974	25.978
1.0	507	4.2466	20.921	25.937
1.5	507	4.2398	20.920	25.928
1.8	507	4.2397	20.897	25.925

Table. 4. Effect of crack length on natural frequency of cracked aircraft wing structure

Crack length (mm)	Depth of crack (mm)	Frequency, f_n (Hz)
0	0	4.2814
570	1.8	4.2397
600	1.8	4.2395
650	1.8	4.2379
700	1.8	4.2370
730	1.8	4.2160

Thereafter, the effect of the crack length on the natural frequency of cracked aircraft wing structure is investigated with triangular crack incorporated numerically at different location (i.e. 492.15, 3457.89, 214.44) having different crack depths of 1.8mm, 1.5mm, 1.0mm, 0.5mm and 0.2mm with constant crack length of 0.507m. The width of the crack is assumed as 0.078m. The numerical simulations shown in Table 6 indicate the natural frequencies of the cracked structure are function of crack location also. First three natural frequencies are decreasing with increasing crack depth at that location.

Table. 5. Effect of depth of crack on natural frequency of cracked aircraft wing structure

Depth of crack (mm)	Crack length (mm)	Frequency, f_n (Hz)		
		First	Second	Third
0	0	4.2814	21.632	26.083
0.2	507	4.2550	20.984	25.959
0.5	507	4.2541	20.973	25.953
1.0	507	4.2522	20.954	25.949
1.5	507	4.2494	20.938	25.943
1.8	507	4.2332	20.875	25.933

5. Conclusion

In the present study, a numerical modal analysis is carried out to investigate the effect of crack length, depth and crack location on the aircraft wing structure. Both uncracked and cracked aircraft wing structure are modelled and analysis is performed using finite element based software platform. The natural frequency for the uncracked aircraft wing model is obtained from numerical analysis which are validated with the results reported in literature. The comparative result shows that the numerical modal analysis procedure for the aircraft wing is correct. Following the same procedure and investigate the numerical model analysis of aircraft wing at different crack length and different depth of crack. It is concluded that the frequency is a function of crack length and depth of crack. An investigation on frequency is carried out with triangular crack at different location with same crack geometry. The result show that frequency is changing when the crack location is changed. The natural frequencies of the cracked wing are decreasing with increase in the of crack length and crack depth.

References

1. E. Carrera, A. Pagani, and M. Petrolo. Applied Mechanics, 80, 041012 (2013).
2. W. M. Ostachowicz, and M. Krawczuk. Sound and Vibration, 150, 191(1991).
3. V. Khalkar, and S. Ramachandran. Proceedings of the International Conference on Processing of Materials, Minerals and Energy, (2018) December 31; Andhra Pradesh, India.
4. D. Wang, M. I. Friswell, and Y. Lei. Sound and Vibration, 291, 1229 (2006).
5. S. U. Sawant, S. J. Chauhan, and N. N. Deshmukh. AIP Conference Proceedings of the International Conference on Functional Materials, Characterization, Solid State Physics, Power, Thermal and Combustion Energy, (2017) July; Andhra Pradesh, India
6. D. Satpute, P. Baviskar, P. Gandhi, M. Chavanke, and T. Aher. Proceedings of the 5th International Conference of Materials Processing and Characterization, (2016) March; Hydrabad, India.
7. M. T. Das, and A. Yılmaz. Sound and Vibration, 436, 155-164 (2018).