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FREE VIBRATION ANALYSIS OF COMPOSITE AIRCRAFT WING WITH CIRCULAR CUTOUT USING FINITE ELEMENT METHOD

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ABSTRACT

In the present study, the effect of circular cutout in the skin of composite aircraft wing on the natural frequencies was studied by finite element method using ANSYS software version 11. The case which was studied is the presence of circular cutout in the skin of the wing through its thickness. The parameters which were studied are the cutout ratio, the location of cutout along the wing span, the location of the cutout along the wing width and the number of the damaged panels. The results showed that the presence of cutout caused a small decreasing in the natural frequencies. The increasing in the cutout ratio and the number of damaged panels caused a small decrease in the natural frequencies. The variation in the location of the cutout along the wing span and the wing width caused very small effect on the natural frequencies.

Key words: composite wing, circular cutout, free vibration, finite element method.

1- INTRODUCTION

The effects of in-flight damage to commercial transport aircraft caused by a projectiles has recently become an area of great research interest. The sources of damage may include ballistic penetrators, high explosive incendiary projectiles, and shoulder fired surface to air missiles, or man portable air defense systems (1).

Cutouts in structural members like aircraft wings made of composite laminates may result in a change in dynamic characteristics. Cutouts make the structure constitutionally weak and reduce its strength . Its effects are likely to be quite considerable when the plate is undergoing large oscillations, especially in space craft or aircraft structures where thin skins are used . Also these composite plates have to resist large seismic and wind loads which may cause exceptionally high stress concentrations especially at the regions where cutouts are provided(2)

Many researchers studied the effect of cutout in dynamic, static and buckling analysis of plate and shells.

Howard J.(3)(2011) designed a rectangular wing model with a hole where the hole simulates damage. The wing is modeled as a thin, uniform, elastic plate using the finite element method. The hole location varied in span wise location. The theoretical flutter velocity and frequency were validated against test conducted at Duke University subsonic wind tunnel .The simulation showed that if the threat impacts on a dry structure (no fuel) it will penetrate through both wing surfaces and produce hole size larger than the missile diameter. If the threat impacts on a wet structure (fuel tank) and does not detonate, the resulting hydrodynamic ram damage could be significant due to the high pressure generated in the fluid.

Luay et al.(4)(2012) worked on the effect of crack depth and position on natural frequency of simple supported beam. Three approaches were employed , an analytical approach is compared with experimental result and with that gained numerically by ANSYS program to verify the result. The results showed that the increasing of the crack depth decreases the natural frequency of the beam, the natural frequency of the beam is lower when the crack is in the middle of the beam than when the crack near the ends position.

Pritish et al.(5) (2013) studied the preliminary sizing and analysis of a wing box. The main objective is to fix appropriate structure within the give envelope. Sizing is done by using classical engineering theories and finite element packages(MSC Nastran and MSC Patran). From the analysis, structure has been optimally designed which satisfies the strength and stability criteria, which still has a scope for optimization by redesigning components like ribs and spars.

Srivastava et al.(6) ,(2013) explored the vibration characteristics of stiffened plates with cutouts subjected to in-plane partial edge at one end at the plate boundaries using the finite element method. Buckling loads and vibration frequencies are determined for different cutout ratios and extent of partial edge loading at one end. The numerical results for a simply supported stiffened square plate having one central stiffener with a central square cutout, showed that the buckling resistance decreases as the cutout size increases in all the modes. Also the results showed that the vibration frequencies increase with the increase of cutout size.

Girish (7) ,(2013) developed a finite element (FE) model of laminated composite skew plates with and without cutouts (circular, rectangular and square) and analyzed the static and free vibration behavior. The composite laminate was modeled in ANSYS finite element package .The parametric effects discussed are (modular ratio, support conditions, ply orientations, number of layers, thickness ratio, geometry of cutout, cutout side to plate side ratio and skew angle). The effect of cutout on skew plate shows that the deflections are decreasing as the cutout size increase, the natural frequency is increasing for both skew angle and cutout size and it decreases for moderately thick to thin skew plates.

Abin et al.(8), (2014) carried out buckling analysis to a standard aircraft wing . The initial design was found to buckle. Several design modifications were made to make the design safe in buckling .Linear static analysis is also carried out. The buckling load of upper skin subjected to compression was analyzed with FEM approach and verification through analytical approach. Buckling analysis is carried out for a number of design modifications. Finally the buckling factor is obtained greater than one and hence it is concluded that buckling does not take place.

Jayashankarbabu et al.(9) (2014) investigated the effect of the size and shape of concentric circular, square and rectangular cutouts and the impact of the plate thickness on the buckling load of all-round simply supported isotropic square plate subjected to uniform inplane uniaxial and biaxial compression loadings. To carry out the study, ANSYS software has been used with 8 shell93 element. Is found that cutouts have considerable influence on the buckling load factor k and the effect is larger when cutout ratios greater than 0.3 and for thickness ratio greater than 0.15.

In the present study, the effect of circular cutout on the natural frequency of composite wing was studied using finite element method ANSYS. The affected parameters which are studied are cutout ratio, the position of the cutout along the wing span and along the wing width, the number of the damaged panels. It is found that the presence of cutout in the skin panels produce a small decreasing in the natural frequencies. The increasing in the cutout ratio and the number of damaged panels caused a small decreasing in the natural frequencies. The variation in the location of the cutout along the wing span and the wing width effected in very small change on the natural frequencies of the wing.

2- THE WING MODEL CHARACTERISTICS USED IN THE ANALYSIS

The wing model used in the present analysis is shown in Fig.(1) , the wing is composed from front and rear spars, 9 ribs and skin. Table (1) shows the standard dimensions and NACA section profile of the wing model. The material of the wing is (carbon – epoxy) composite with a properties stated in Table(2). The wing shell is of (2mm) thickness which is of 8 layers, the thickness of each layer is 0.25mm, with a symmetric ply orientation $(45/0/45/0)_S$.

3- FINITE ELEMENT METHOD (FEM)

The natural frequencies of the wing were calculated numerically by the (FEM) using ANSYS software package version 11. The layered element shell 99 which is used in the analysis is shown in Fig.(2). The wing was constrained in all degrees of freedom at its root that are (UX=0, UY=0, UZ=0, ROTX=0, ROTU=0 and ROTZ=0), Fig.(3) shows the boundary conditions applied and the mesh of the model.

4-RESULTS AND DISCUSSION

Fig.(4) shows the cutout in the wing skin with different cutout ratios and different locations along the wing span. The cutout ratio is (d/D) where d is the hole diameter and D is the panel side (D=0.575m). Fig.(5) and Fig.(6) show the 1st and 2nd natural mode shapes at (d/D)=0.2 at the root and tip panels along the wing span respectively.

Table(3) and Fig.(7) show the natural frequencies for various values of cutout ratios when the cutout at the root panel between front and rear spar which is the case stated in Fig.(4-a).

Table(4)and Fig.(8) show the natural frequencies for various locations of the cutout in the root panel along the wing width (x-axis) at (d/D)=0.2.

Table(5) and Fig.(9) show the natural frequencies for different locations of the cutout along the wing span when the cutout at the panel between front and rear spar at (d/D)=0.2.

Table(6) and Fig.(10) show the natural frequencies at various numbers of damaged panels along the wing span at (d/D)=0.2 which is the case stated in Fig.(4-c).

The results stated that the increasing in the cutout ratio decreases the natural frequencies where the natural frequency of the 1st mode is (19.107Hz) when there is no cutout and (17.080Hz) at (d/D)=0.7.

Also the results showed that the increasing in the numbers of damaged panels along the wing span decreases the natural frequencies in very small values, when the number of damaged panels is 2 the 1st and 2nd natural frequencies are(17.805, 54.154) while when the number of damaged panels 5 the frequencies are(17.116, 53.317) that there are very small decrease .

From the results it is found that the variation in the location of cutout along the wing width and the wing span caused a very small change in the values of natural frequencies that the natural frequencies may be considered as constant with the variation of cutout position along the wing width and the wing span.

5- CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

From the results of the presents study may be conclude that:

1. The increasing in cutout ratio causes a small decrease in the natural frequencies.
2. The increasing in the number of damaged panels causes a small decreasing in the natural frequencies.
3. The effect of cutout location along the wing span and the wing width on the natural frequencies is very small and may be neglected that the natural frequencies may be considered as constant with the variation of cutout location.

In a future work, the following steps may be suggested for studying:

1- Comparison for different hole shape (triangular, square or other shape).
2- Stress analysis of the wing with a damaged panel.
3-The analysis of impact between a projectile and a wing .

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Table(1) The characteristics of the wing model(10).

Wing span (m)	4.6
Taper ratio	0.44
Root chord(m)	2.03
Tip chord(m)	0.8932
Wing root section profile	NACA 23015
Wing tip section profile	NACA 23012

Table(2) The material properties of (carbon-epoxy) composite (11).

EX (Gpa)	147
EY(Gpa)	10.3
EZ (Gpa)	10.3
PRXY	0.27
PRYZ	0.34
PRZX	0.27
GX (Gpa)	7
GY (Gpa)	3.7
GZ (Gpa)	7
Density (kg/m^3)	1600

Table (3) Natural frequencies for different cutout ratios, the cutout is at the center of the root panel between front and rear spar.

Serial number	Cutout ratio	1st mode natural frequency (Hz)	2nd mode natural frequency (Hz)
1	0	19.107	54.799
2	0.1	18.792	54.797
3	0.2	18.696	54.767
4	0.3	18.210	54.648
5	0.4	18.145	54.586
6	0.5	17.098	54.362
7	0.7	17.080	53.696

Table (4) Natural frequencies when the cutout in the center of various wing root panel location along the wing width (x-direction) with (d/D)=0.2 .

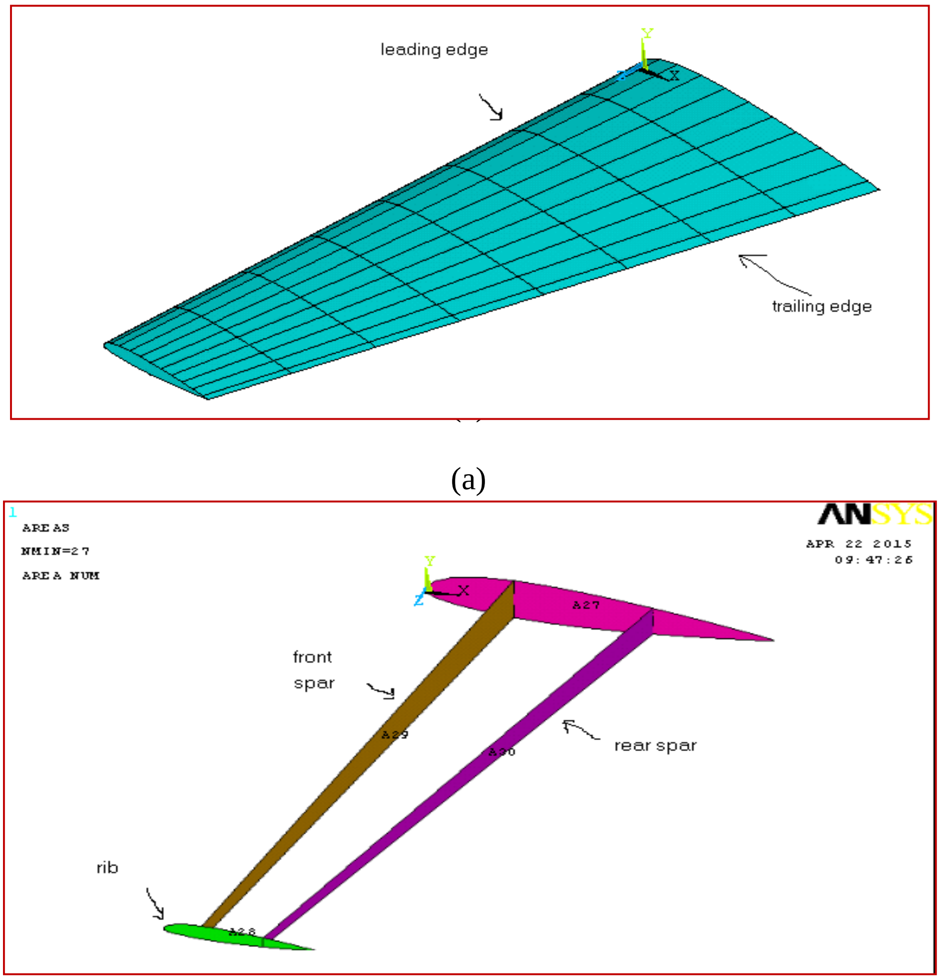
Serial number	X(m)	1st mode natural frequency (Hz)	2nd mode natural frequency (Hz)
1	0.25375	18.888	54.759
2	0.812	18.696	54.767
3	1.67475	19.096	54.907

Table (5) Natural frequencies when the cutout in various panel location along the wing span (Z-direction) with (d/D)=0.2 .

Serial number	Z(m)	1st mode natural frequency (Hz)	2nd mode natural frequency (Hz)
1	0.2875	18.696	54.767
2	0.8625	18.567	54.790
3	1.4375	18.613	54.687
4	2.0125	18.738	54.527
5	2.5875	18.951	54.465
6	3.1625	19.047	54.524
7	3.7375	19.126	54.719
8	4.3125	19.165	54.835

Table(6) Natural frequencies for the cutout in different numbers of damaged panels along the wing span with (d/D)=0.2.

Serial number	Number of damaged panels	1st mode natural frequency (Hz)	2nd mode natural frequency (Hz)
1	0	19.107	54.799
2	1	18.210	54.648
3	2	17.805	54.442
4	3	17.447	54.154
5	4	17.242	53.779
6	5	17.116	53.317

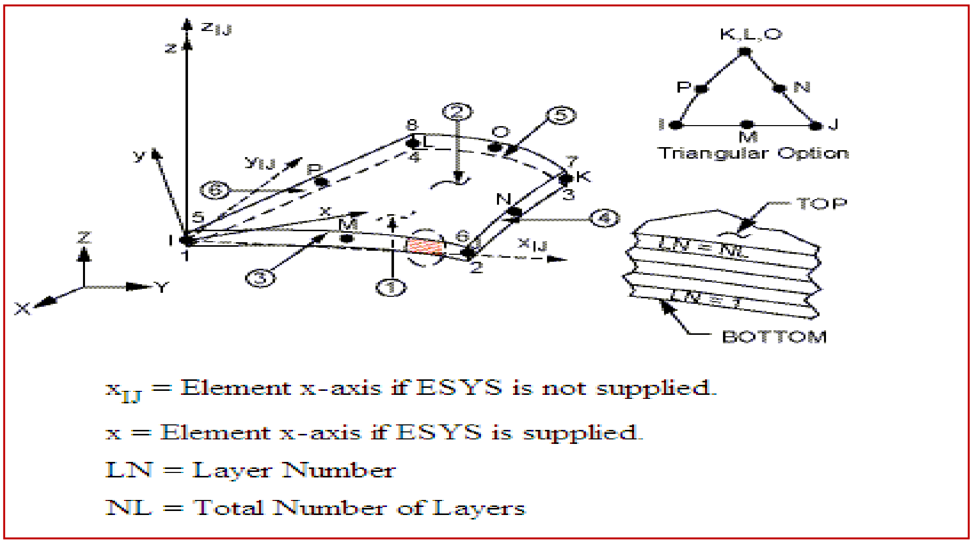


(a)

(b)

Figure (1) The wing model used in the Analysis

a) Complete model .
b) The locations of spars with respect to ribs.



x_{IJ} = Element x-axis if ESYS is not supplied.

x = Element x-axis if ESYS is supplied.

LN = Layer Number

NL = Total Number of Layers

Figure (2): Shell99 Element

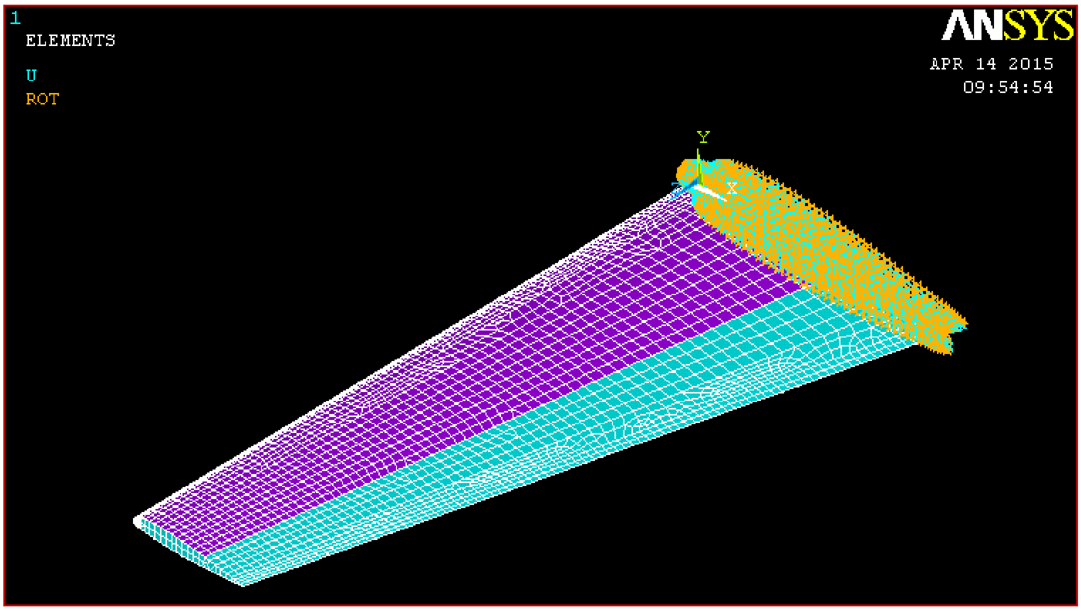
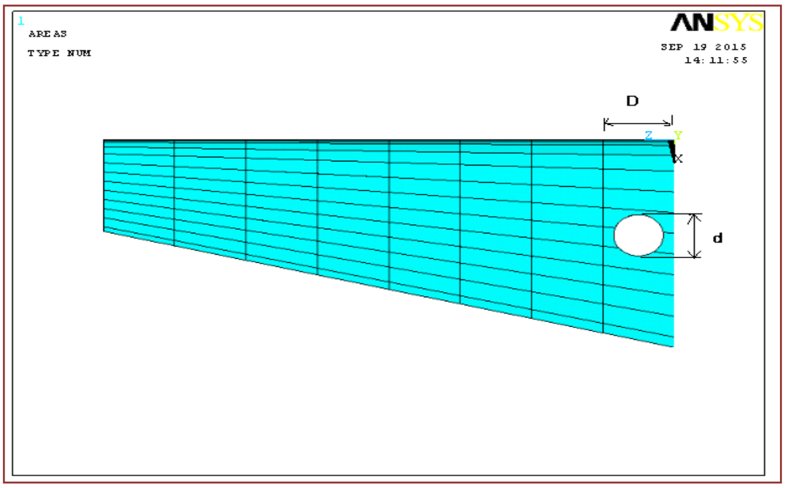
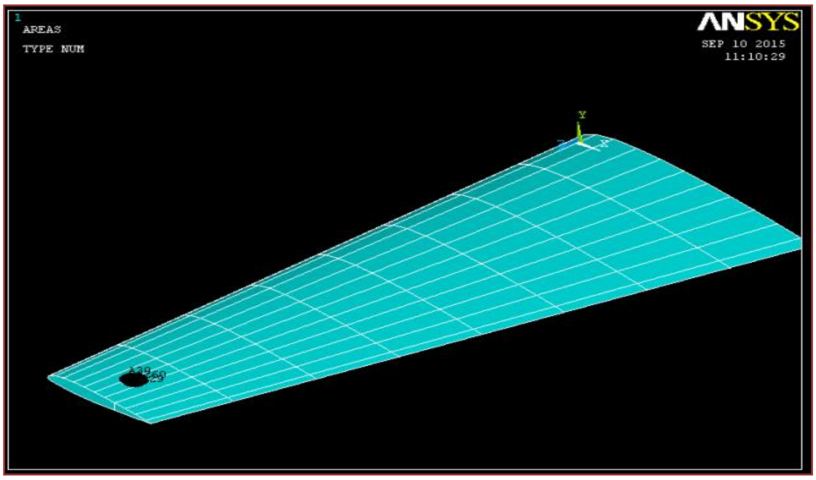


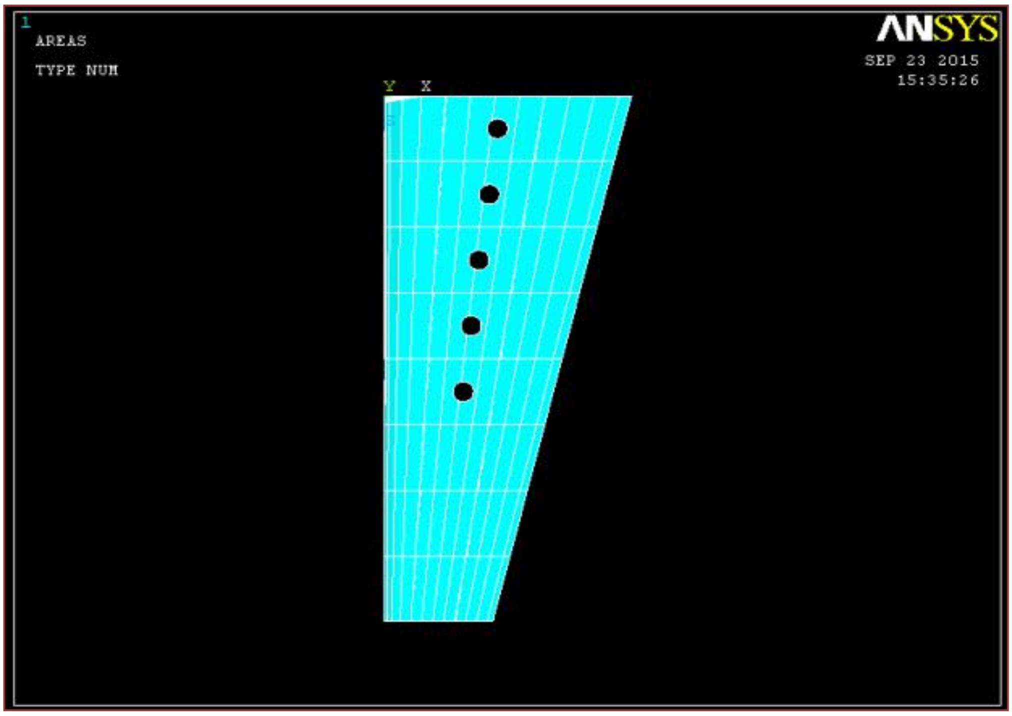
Figure (3) Boundary Conditions and meshing of the Wing.



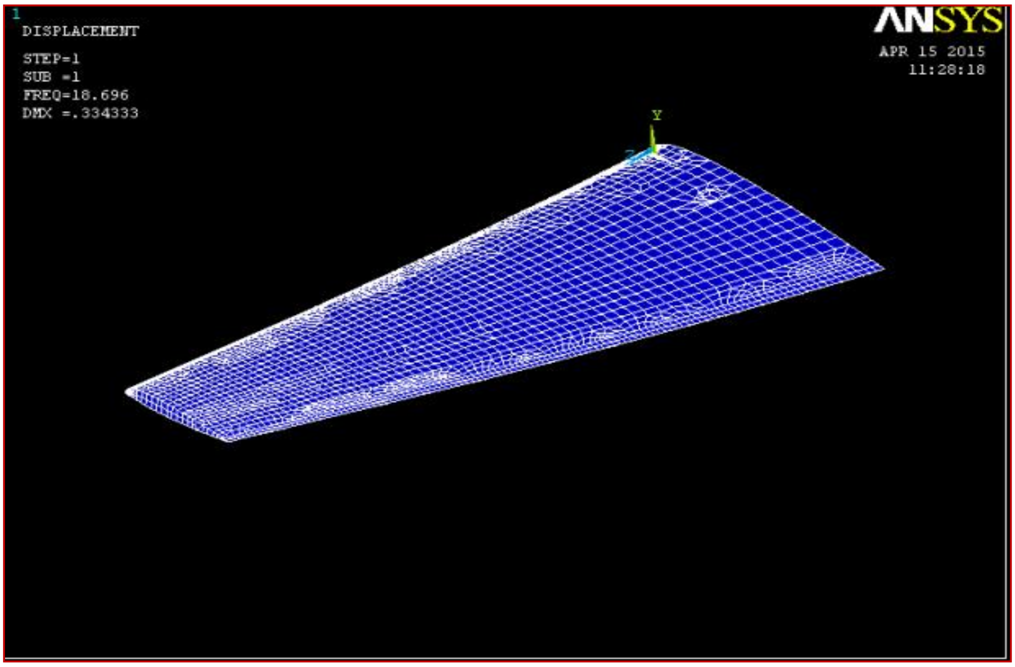
(a) Cutout at the center of the panel between front and rear spar with cutout ratio=0.7.



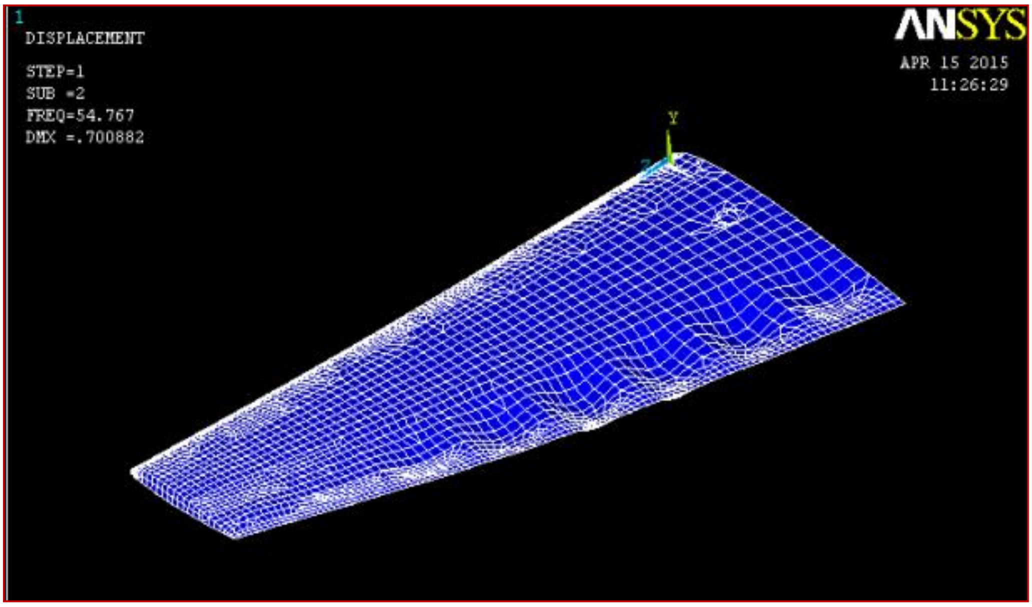
(b) Cutout at the center of tip panel between front and rear spar with cutout ratio= 0.2.



(c) Cutout at the center of five panels along the wing span with cutout ratio=0.2.
Figure (4) Cutout in a different panels locations and different cutouts ratios.

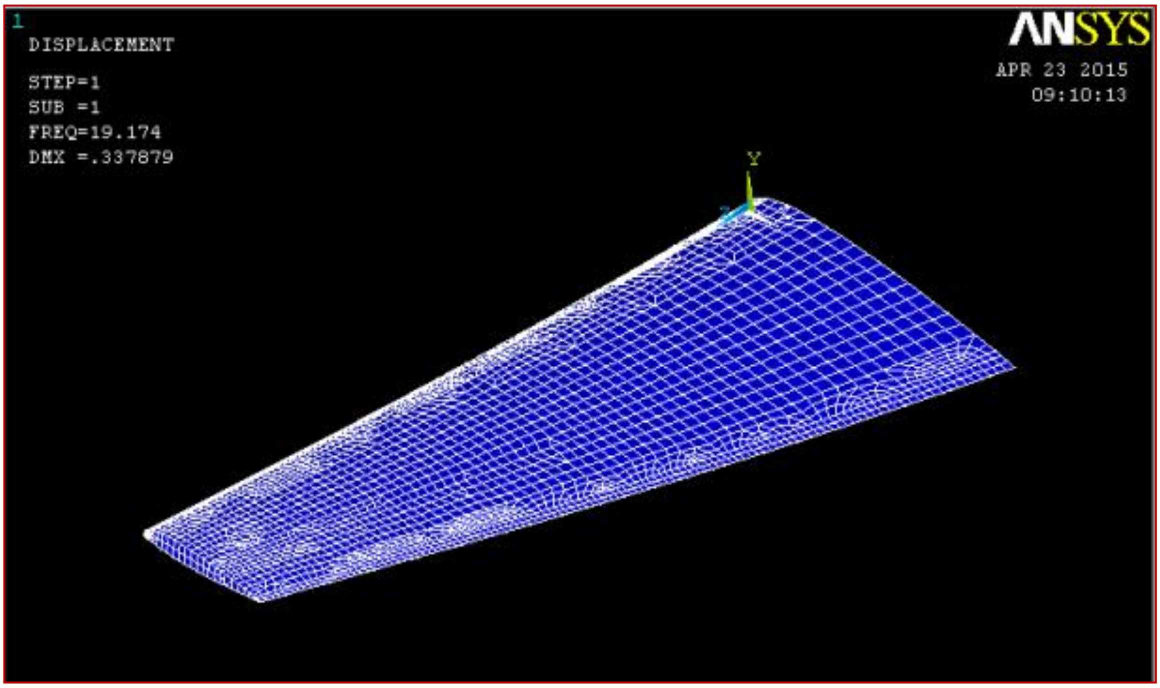


(a)

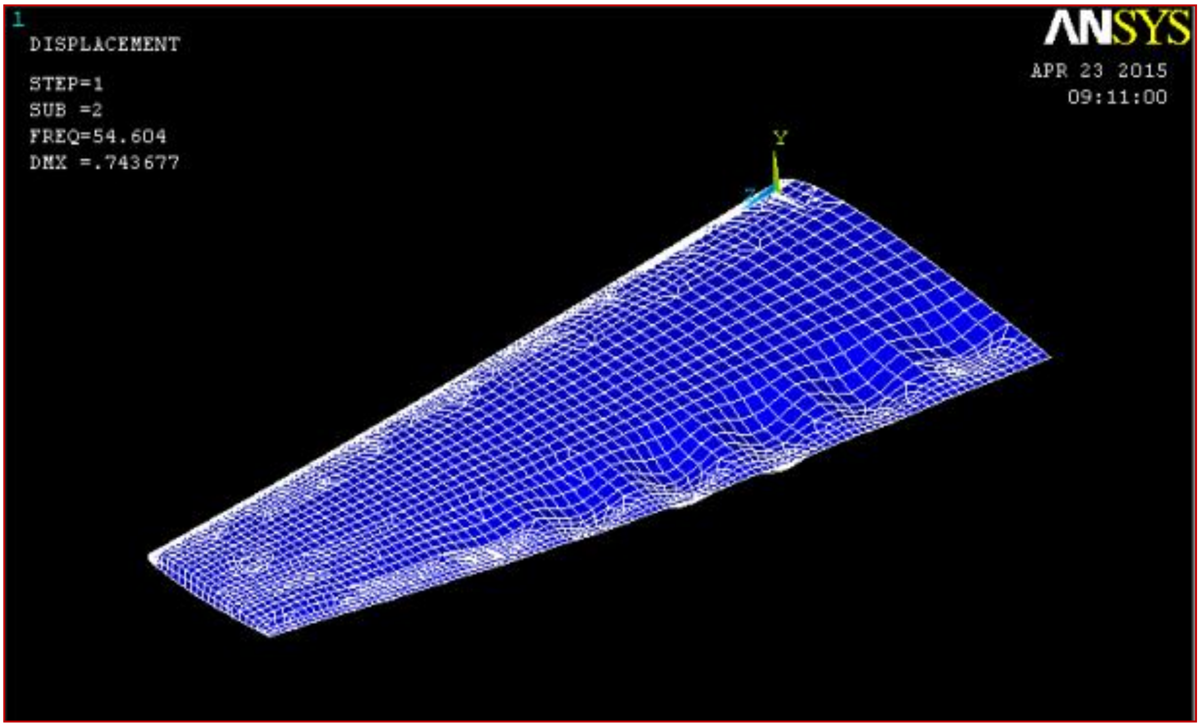


(b)

Figure (5) Natural mode shapes when the cutout at the center of the root panel between front and rear spar at (d/D)=0.2. (a) first mode (b) second mode.



(a)



(b)

Figure (6) Natural mode shapes when the cutout at the center of the tip panel between front and rear spar at (d/D)=0.2. (a) first mode (b) second mode.

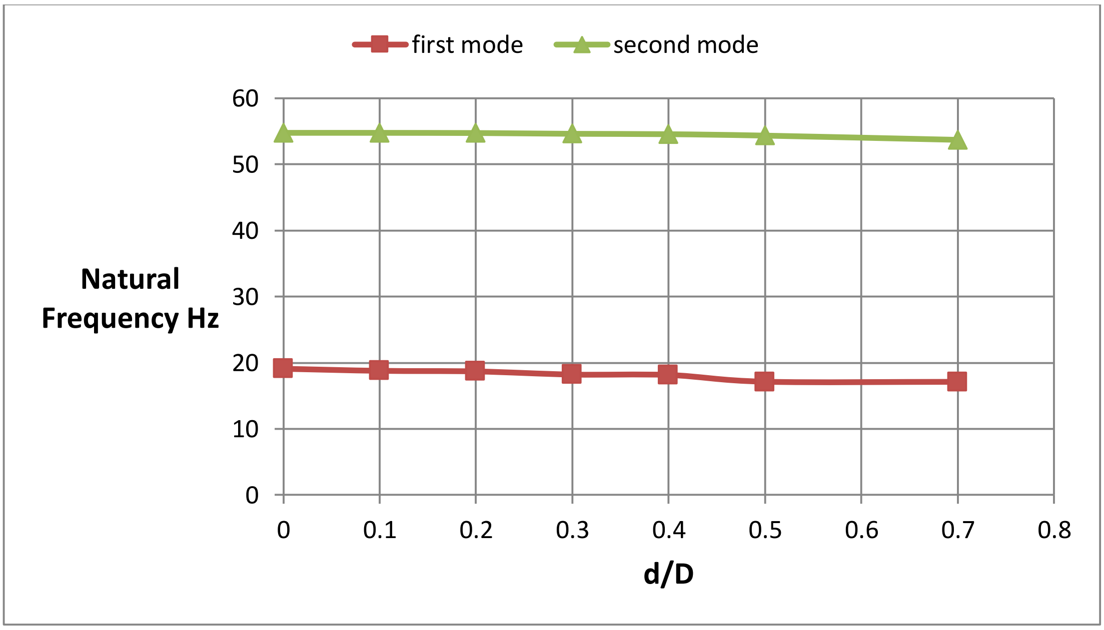
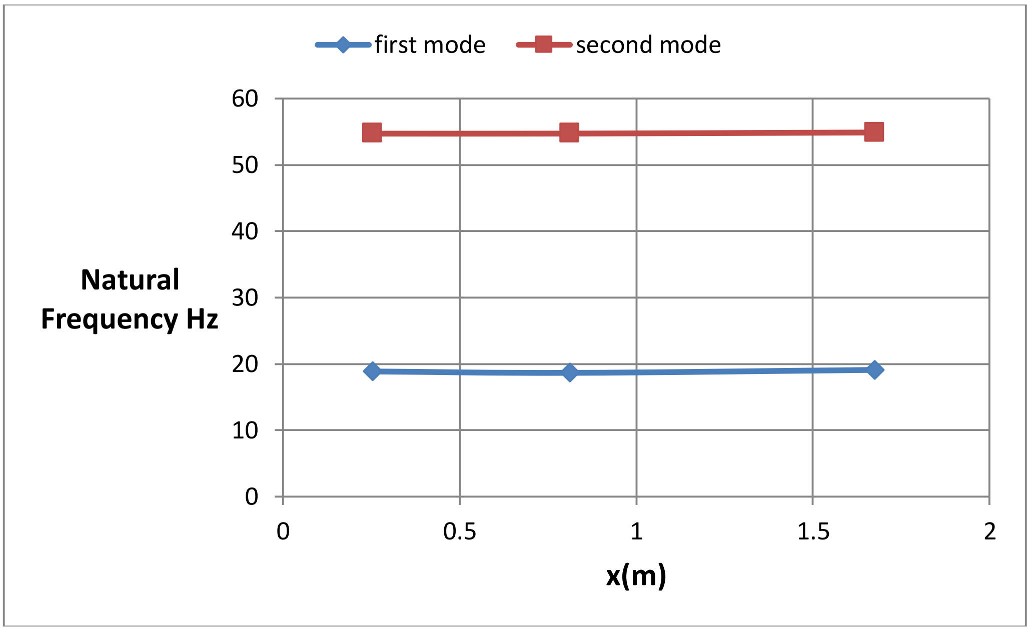
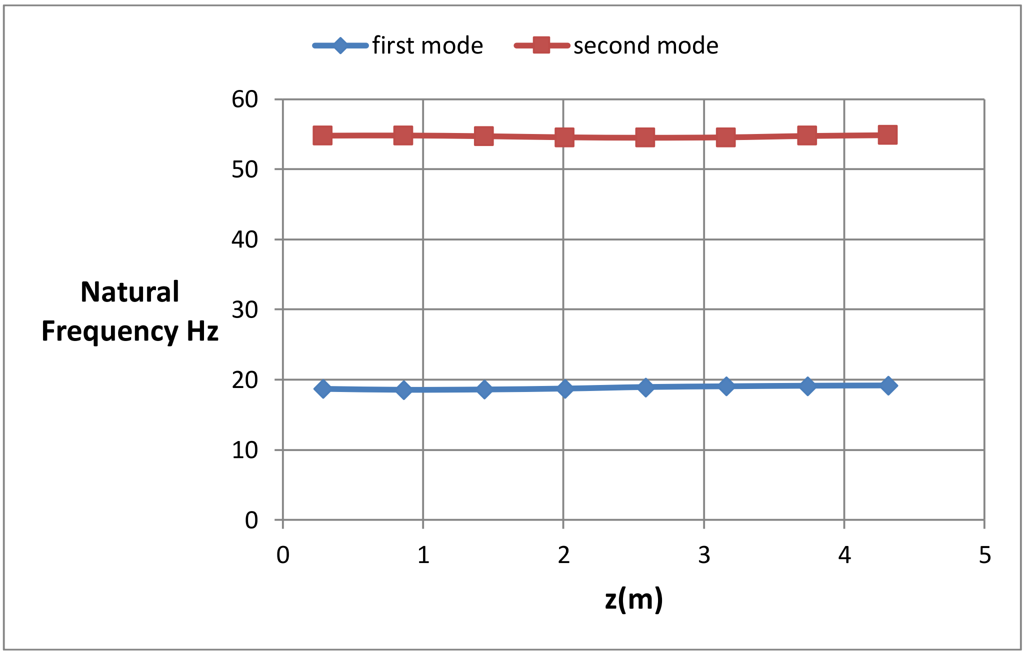


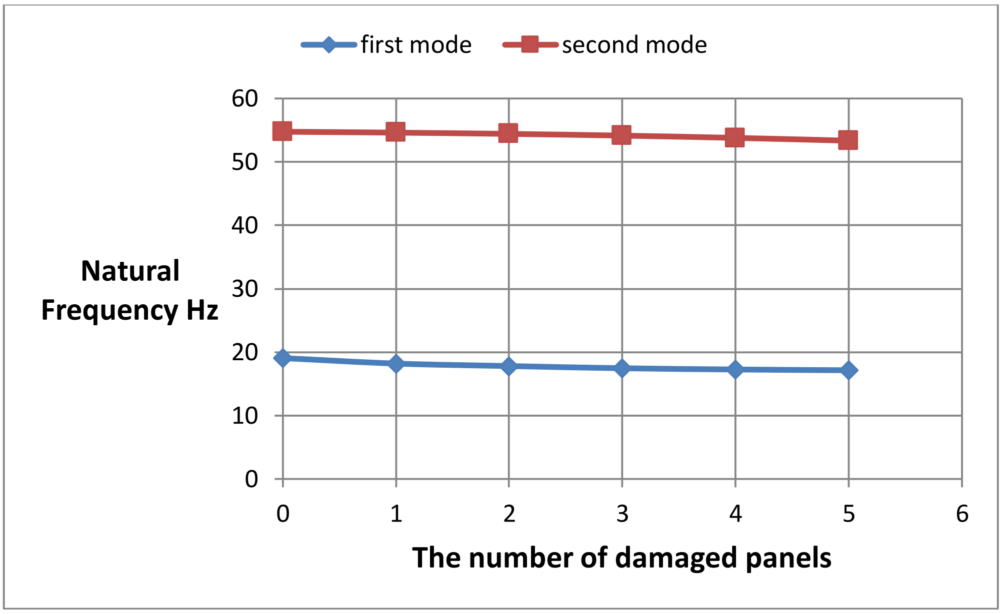
Figure (7) The effect of cutout ratio on the natural frequencies.



Figure(8) The effect of the damage panel location along the wing width (x-direction)on the natural frequencies.



Figure(9) The effect of the damage panel location along the wing span (z-direction)on the natural frequencies.



Figure(10)The effect of the number of damaged panels on the natural frequencies.

تحليل الاهتزاز الحر لجناح طائرة مركب يحتوي ثقب دائري المقطع

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الخلاصة

في هذا البحث تم دراسة تأثير وجود ثقب دائري المقطع على الترددات الطبيعية لجناح طائرة مصنوع من مواد مركبة بطريق العناصر المحددة باستخدام برنامج الانسز 11. تم عمل ثقب دائري المقطع في الجناح بعمق يساوي سمك الجناح وبأقطار مختلفة ومواقع مختلفة على طول وعرض الجناح لمعرفة تأثير اللوح المتضرر من الجناح على الترددات الطبيعية . نتائج البحث بينت إن زيادة قطر الثقب الدائري نسبة الى طول لوح الجناح وكذلك زيادة عدد الالواح المتضررة يؤدي الى نقصان الترددات الطبيعية بمقدار قليل . كذلك بينت النتائج ان تغيير موقع الثقب الدائري على طول وعرض الجناح يؤثر بمقدار ضئيل جدا على الترددات الطبيعية للجناح.

كلمات مفتاحيه :جناح مركب , ثقب دائري , الاهتزاز الحر , طريقة العناصر المحددة.