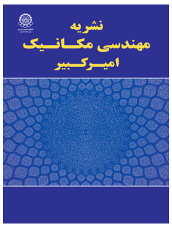

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Aeroelastic analysis of a thin composite plate, with the effect of general and local geometric defects

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ABSTRACT: In this study, the effect of laminate type and number of layers, fiber angle and modulus of elasticity in combination with the effect of global and local geometric defects has been investigated as a new combination in the field of aeroelasticity. Using the principle of virtual work, by directly integrating the problem-solving boundary, the governing equations are determined based on Kirchhoff thin-plate theory. Then, using the assumption mode method in Galerkin's theory, the partial differential equations are converted to ordinary nonlinear differential equations. The final nonlinear equations are solved using the Runge–Kutta numerical method and the time domain results are extracted to determine the flutter and post-flutter behavior of the plate. The results of the analysis showed that the geometric defect with non-uniform and asymmetric load production, the type of layering, the number of layers and mechanical loads are effective on the plane flutter boundary. The effect of local geometric defects in determining the flutter border is not necessarily destabilizing, but in some cases, depending on the size and location of the defect, it is also possible to increase the stability of the plane flutter boundary. In addition, the dynamic behavior of the plate under the effect of local geometric defects with different shapes and dimensions is very diverse and different from the of general defect (first mode shape) or shell with small curvature.

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1- Introduction

Plates of composite materials are widely used in aerospace, automotive, marine and civil industries. The results of past researches show that a static pressure difference applied to a curved plate changes the flutter behavior of the plate in a way that is qualitatively similar to the experimental results for a cylindrical shell [1]. Flutter of two-dimensional curved plate was analyzed by Dowell [2, 3] and its wind tunnel test was performed by Andersen. The theoretical results of the flutter analysis of the two-dimensional curved plane of Dowell [2, 3] are qualitatively consistent with Andersen's experimental results [4]. Mousazadeh and Mohammadi [5] investigated the effect of large deformations on the change of the flutter boundary of a thin plate under non-uniform thermal loads and temperature-dependent properties using the first and third order piston theories. Recently, Tian *et al*. [6] proposed a theoretical model of a metamaterial reinforced plate with multiple reinforcing beams to reduce vibrations and analyze supersonic flutter. In this article, the effect of general and local geometric defects, in combination with the layering type of thin composite material, along with the effect of external aerodynamic loads, has been investigated.

2- governing equations

2- 1- Structural relationships

The curved panel model under the effect of supersonic aerodynamic flow and the effect of external aerodynamic loads and pressure force inside the plane is shown in Figure 1.

U_∞ , is the speed of the free flow on the plate, R_x , is the force inside the plate, P^d , is the dynamic pressure of the flow above the plate, P^s , is the static pressure under the plate, h , is the thickness of the plate and the a is length of the plate. The dynamic form of the principle of virtual work is in the form of relation (1).

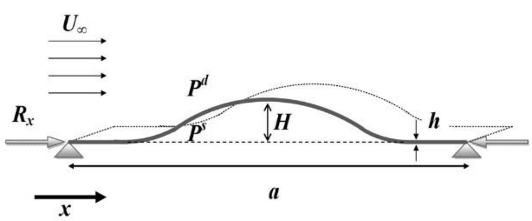

Fig. 1. Three-dimensional shell geometry model under the effect of external loads

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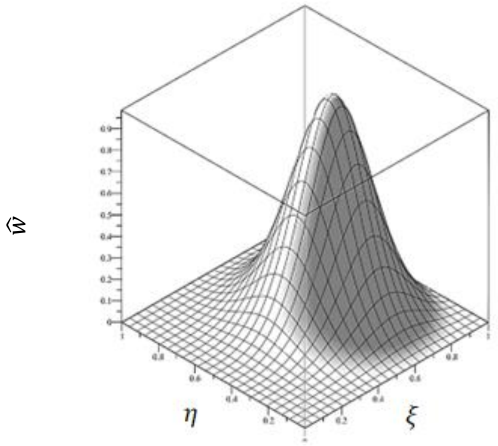

Fig. 2. Local defect, width 0.65, location 0.7

$$0=\int_0^T(\delta U+\delta V-\delta K)dt \tag{1}$$

In the above relationship δU , is the virtual strain energy, δV , is the virtual work done by the applied force, δK , is the virtual kinetic energy, and the Euler-Lagrange equations are obtained by separately setting the coefficients of the constants, δu_0, δv_0 and δw_0 on the solution space Ω_0 to zero.

$$\begin{aligned}
&\delta u_0:\ \frac{\partial N_{xx}}{\partial x}+\frac{\partial N_{xy}}{\partial y}=I_0\ddot{u}-I_1\frac{\partial \ddot{w}_0}{\partial x},\\
&\delta v_0:\ \frac{\partial N_{xy}}{\partial x}+\frac{\partial N_{yy}}{\partial y}=I_0\ddot{v}-I_1\frac{\partial \ddot{w}_0}{\partial y},\\
&\delta w_0:\ \frac{\partial^2 M_{xx}}{\partial x^2}+2\frac{\partial^2 M_{xy}}{\partial y\partial x}+\frac{\partial^2 M_{yy}}{\partial y^2}+N(w_0+\hat{w})+q=I_0\ddot{w}_0\\
&\qquad -I_2\left(\frac{\partial^2\ddot{w}_0}{\partial x^2}+\frac{\partial^2\ddot{w}_0}{\partial y^2}\right)+I_1\left(\frac{\partial \ddot{u}_0}{\partial x}+\frac{\partial \ddot{v}_0}{\partial y}\right).
\end{aligned} \tag{2}$$

2- 2- Aerodynamic relationships

Aerodynamic relationships along the x axis have been used. There is the ability to simulate the flow based on the first and third order piston theory. The term q is related to the effect of the external load placed by ΔP . The interaction between the structure and the fluid is considered based on the nonlinear piston theory. The relation of isentropic pressure on the plate using the piston theory based on the vertical speed of the flow on the plate, V_z , (Downwash speed) in one dimension is shown as equation (3) [6].

$$P^d(x,t)=P_\infty\left(1+\frac{\gamma-1}{2}.\frac{V_z}{c_\infty}\right)^{2\gamma/\gamma-1}. \tag{3}$$

By expanding the relation (3) to the first and third order, the piston model of the first and third order is obtained.

Table 1. Structural properties and environmental flow conditions

$T\,300/5208$	G_{13}=7.17 Gpa	$\rho_\infty=1.225\ kg/m^3$
$\nu_{12}=0.28$	G_{23}=6.21 Gpa	$a=b=1\ m$
E_1=181 Gpa	n=10 layers num.	$h=0.01$
E_2=10.3 Gpa	$\rho_m=1600\ kg/m^3$	$C_\infty=340\ m/s$
G_{12} = 7.17 Gpa		$\gamma=1.4$

$$P^d(x,t)=P_\infty\left(1+\gamma\frac{M}{\beta_1}\left(\eta_1\frac{V_z}{c_\infty}\right)\right). \tag{4}$$

$$\begin{aligned}
&P^d(x,t)=P_\infty\left(1+\gamma\frac{M}{\beta_1}\left(\eta_1\frac{V_z}{c_\infty}\right)+\right.\\
&\left.\left[\frac{\gamma(\gamma+1)}{4}\right]\frac{M}{\beta_1}\left(\eta_1\frac{V_z}{c_\infty}\right)^2+\frac{\gamma(\gamma+1)}{12}\frac{M}{\beta_1}\left(\eta_1\frac{V_z}{c_\infty}\right)^3\right).
\end{aligned} \tag{5}$$

Where is defined as $\eta=\frac{M}{\sqrt{M^2-1}}$. To determine the dynamic aerodynamic pressure on the plate, the relationship of the downwash speed due to the fluid flow above the plate is defined based on the vertical deformation of the plate [2].

$$V_z=\left(\beta_2 w_{0,t}+U_\infty(w_{0,x}+\hat{w}_{0,x})\right) \tag{6}$$

Some types of local 3D defects are shown in Figure 2. The purpose of the image of the types of defects is to know the types of defects to be investigated and studied. Recognition of the examined defect model is specified by the present forms. The purpose of this defect model is to investigate the effect of creating a geometric defect that has caused the plane to be distorted in one direction due to environmental and external thermal loads.

3- Numerical results

3- 1- Structure response under environmental conditions

The analysis of the composite material plate is graphite-epoxy according to Table 1.

Figure 3. Dimensionless dynamic stress related to thin non-linear plate flutter (thickness to plate length ratio 0.01) based on defect height 0 to 1.2, with 45 and 60 degree symmetrical lamination (8 layers), for defect width 0.9 comparison has been.

With the increase of the height of the defect, the dynamic pressure of the flutter has decreased. For symmetric 45 degree lamination, the decrease of flutter speed according

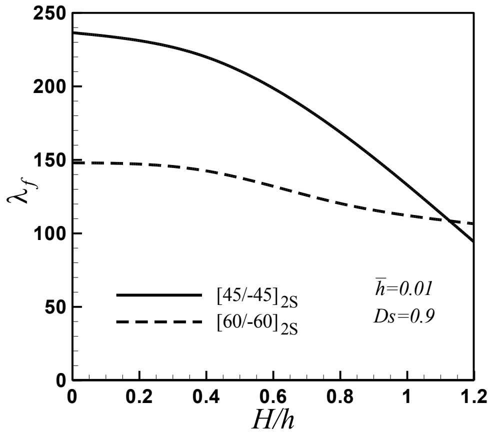

Fig. 3. A 45 degree symmetrical layering

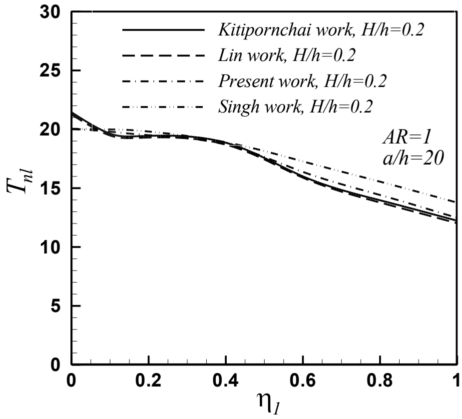

Fig. 5. Comparison of the time course of the page with the overall defect effect of 0.2

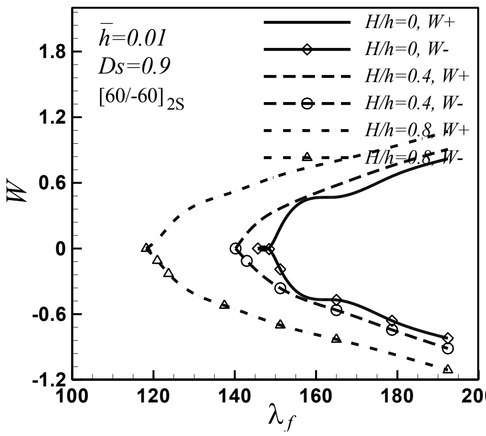

Fig. 4. Positive and negative amplitude of the maximum displacement of the plate with 60 degree symmetrical layering

Table 2. Properties of the structure [8]

$H/h = 0.2$	$G_{12} = 26\,Gpa$	$\rho_m = 2700\ kg/m^3$
$\nu_{12} = 0.3$	$E_1 = 70Gpa$	$a/h = 20, 40$

to the defect height has occurred with a greater slope than for 60 degree lamination. With the increase of the layering angle from 45 to 60 degrees, the flutter speed has generally decreased. Figure 4 shows the positive and negative range of the maximum displacement of the plate with 60 degree symmetrical layering, according to the dynamic pressure of the flutter and the height of the defect is 0 to 0.8. In the 60-degree layering, the displacement range is constantly increasing with the increase of the dimensionless dynamic pressure.

3- 2- Verification

The research of Kitipornchae et al. [8] is related to the nonlinear vibrations of the FGM plate with the effect of local geometric defects.

Material properties and problem information are stated in Table 2.

A comparison of the frequency of the plate with the effect of the defect and the change of excitation applied to the plate has been made in Figure 5. The boundary conditions of simple support, isotropic plane with symmetric layering and general sinusoidal geometric defect are assumed.

3- 3- Conclusion

The most important results are summarized below:

• By increasing the height of the overall defect, the dynamic pressure of the flutter has decreased.

• For symmetric 45 degree layering, the flutter speed decrease according to the defect height has occurred with a greater slope than for 60 degree layering. Therefore, the 45 degree lamination is much more affected by the overall defect effect

than the 60 degree lamination. The stiffness of the structure in 45° layering is more than 60° in the flow direction. Therefore, the higher the stiffness of the structure, the more effective the effect of defects in reducing the flutter border.

• By increasing the layering angle from 45 to 60 degrees, the flutter speed has generally decreased. The reason for that is the reduction of the stiffness of the structure in the flow direction by increasing the angle of the porcelain layer.

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