Design And Analysis Of Composite Panel In An Aircraft Wing

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Abstract: In this work, the analytical design of a composite plate which is majorly used in an aircraft wing or internal plate in a missile system is designed and analyzed. These plates are subjected to different in-plane loads and out-plane loads which may result in buckling and bending and may cause vibration in the plate. The maximum central deflection and uni-axial critical buckling load of the plate with different layups with CCCC boundary condition is found, by the code written in MATLAB. The governing equations for plate analysis are solved using Rayleigh-Ritz approximation method satisfying the essential boundary conditions of the plate which is subjected to bending and buckling loads. The composite plate with the optimum layup is fabricated using the Hand-Layup process. The Bend load test is performed on the fabricated plate to find the deformation by applying maximum load. Experimental and Numerical results are compared and presented.

1. Introduction

A composite is a term used to describe the macroscopic fusion of two or more components to create a useful third material. The critical step is a macroscopic inspection of a substance whose constituent parts can be seen. Although different materials can be mixed on a microscopic level, as in metal alloying, the resulting substance is macroscopically homogenous, which means that the constituent parts are essentially indistinguishable to the human eye and function as a single unit. The advantage of composite materials is that, with proper design, they frequently display the best characteristics of their individual components and, occasionally, some characteristics that neither component possesses. Composite materials have commercial applications and laminated Glass fiber reinforced composite materials are employed in the aero industry. C.E. Imrak and I. Gerdemeli - worked on Rectangular plates under uniform load, $x = \pm a$, $y = \pm b$, are taken into consideration. An exact solution is presented, in which each term of the series is trigonometric and hyperbolic, and satisfies the boundary conditions on all four edges identically. Their solution consists of three terms, the first of which corresponds to the case of a strip and the other two of which denote the effects of the edges. The solution was obtained using a simple and straightforward method. The numerical values of the deflections are calculated and compared with those of previous papers to demonstrate the method. It is discovered that there is a reasonable agreement between their findings and those of this paper.

The buckling behavior of rectangular plates with cutouts at various locations and subjected to partial edge compression are analyzed using ANSYS to model the plate and obtain results [1]. Plate buckling behavior is investigated for simply supported plates. The mathematical formulations and a closed-form analytical solution for calculating buckling loads of simply supported balanced symmetric laminated composite plates subjected to combined in-plane bi-axial and shear loading are presented [2]. All possible axial and transverse load combinations, i.e., compression and tension, are considered in conjunction with the in-plane shear loads. Buckling analysis considers the effects of both transverse shear deformation and bending-twisting coupling at the same time. Smart structures are those in which piezoelectric layers are attached to elastic layers in patches or in a distributed fashion and are analyzed based on higher-order shear deformation theory[3]. Buckling analysis of composite laminates under an in-plane compression load based on the mesh-free Galerkin Kriging method is presented [4]. The moving Kriging interpolation (MK) technique possessing the delta property is employed to construct the shape functions, and thus no special techniques for imposing the essential boundary conditions are required.

The present formulation is based on the Krichh off-plate theory. The applicability, accuracy, and effectiveness of the method are illustrated through a number of numerical examples. The results calculated by the proposed method are compared with those of existing reference solutions available in the literature and very good agreements are observed. It can be said that the proposed method can be considered an alternative numerical technique in terms of mesh-free methods.

The bending of plates, also known as plate bending, is the deflection of a plate perpendicular to its plane caused by external forces and moments. When two axial forces act on a body from opposite directions we observe a structural deformation of that body which is called Buckling.[8,9,&10].

A laminate is a bonded stack of laminae with different orientations of the material directly in the laminae. A laminate's layers are typically bonded together by the same matrix material that is used in the individual laminae[5&6]. The testing of composites at the laboratories is referred[11].

A thin plate of an airplane wing (Fig.1) is considered for the study.

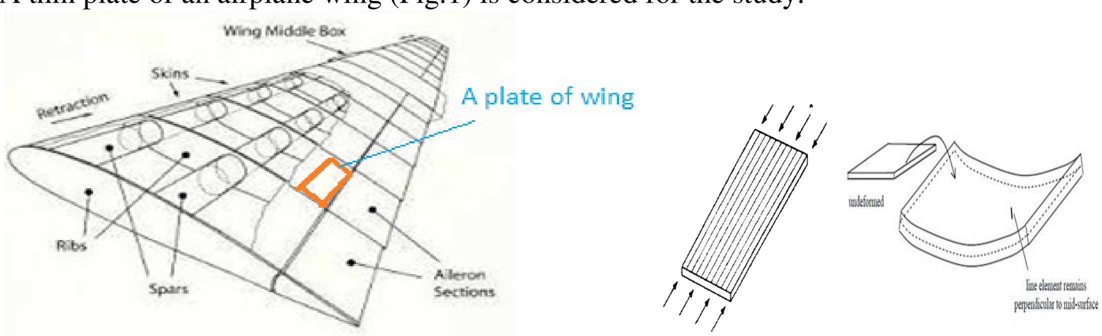


Fig. 1. The Plate Of An Aircraft Wing

2. Analytic Method of Analysis Using Rayleıgh-Rıtz Method

The analytic methods can analyze simple and regular shaped products such as beams, columns, shafts, plates, cylinders, and so on. The products and their loading are specified by mathematical expressions, which are then analyzed using mathematical and scientific theories to provide exact solutions. For the product of complicated sizes and shapes with complicated material properties and boundary conditions, getting solutions using the analytical method is difficult, we may get approximate but acceptable solutions using numerical methods. The three Numerical methods mostly used are

- Finite Element Method
- Finite Difference Method
- Functional Approximation Method

To find solutions to complex problems like non-linear and continuous systems, this method can be used. The physical problems are first written in terms of differential equations or any possible mathematical expressions. By integrating and applying boundary conditions, an approximate solution can be obtained by this method. The variation method, specifically known as the Rayleigh-Ritz method and Weight Residual method are some of the functional approximating methods.

Rayleigh-Ritz method is a direct numerical method for approximating Eigenvalues that had been developed to solve physical boundary value problems. It is a typical variation method in which the principle of the integral approach is adopted for solving most complex structural problems. In this method function of Ritz, parameters are taken as π, which ranges from 1 to ∞.

In this method, the problems are solved in two ways such as:

- Minimum potential energy method.
- Integral approach method.

Even though the above two methods seem to be similar, there is a slight difference in their procedure.

The expression for the displacement function y(x) in terms of polynomial series is obtained as,

$y(x)=a_1+a_2x+a_3x^2+a_4x^3\ldots$.-Eq. 1

a_1,a_2,a_3 are the Ritz parameters or coefficients.

The number of coefficients decides the accuracy of the solution.

The code is written in MATLAB [7] for 1-term and 4-term approximations using the Rayleigh-Ritz method, under Clamped boundary conditions (CCCC) at all edges for Carbon Epoxy composite to find the maximum deflection. Fabrication of the square plate is also done, and a Bend load test is performed on it.

The laminate is a square plate ($0\le x,y\le a$) which is having a total thickness, of h=2.5mm.

Considering the following assumption for the solution:

CCCC: $x_1= x_2(x-a)^2$, $x_2= x_3(x-a)^2$ ------- Eq.2, similarly, $y_1 = y_2(y-a)^2$, $y_2 = y_3(y-a)^2$. --------Eq. 3.

3. Experimentation

3.1. Manufacturing of Laminate

Unlike the other conventional materials, the manufacturing of composite material and its final use have a close relation. The manufacturing process of material is a part of fabrication for the structural component. The material used in this experiment is Uni-directional Carbon fiber epoxy. This material is light in weight and extremely flexible and possesses high strength properties. It allows the component to absorb the high-level force without breakage. These materials are usually used in the replacement of heavy metals in Automotive and Aeronautical Industries

The manufacturing process using steel mould of 320 mm x 320 mm is used in Hand Layup Process as shown in Fig.2, and finally, the required dimension of the plate of 300 mm x 300 mm is made.



Fig. 2a Steel Mould Fig. 2b Adding The Layer Fig. 2c Roller

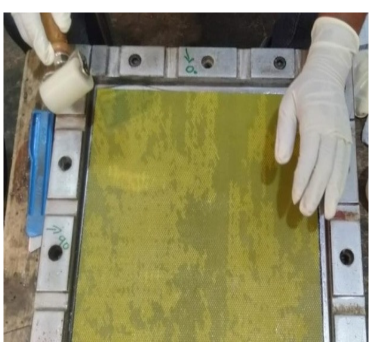


Fig. 2d Rolling On The Layup Fig. 2e Closing The Lid Fig. 2f Placing Steel Mould In Press

Fig. 2. Manufacturing Of Laminate.

3.2. Bend load test of composite plate

A Test Rig that measure, control, and also evaluate a device according to the defined test parameters is integrated using data acquisition hardware. To determine the maximum central deflection of a composite plate, a Hydraulic Actuator is used for applying a central load of 2570 N on the considered composite plate by clamping it on all edges.

Procedure:

- First, the Test setup (Fig. 3) is arranged, then the composite plate is to be fixed under the testing machine.
- To ensure the functionality of the instrumentation, a Load cycle of 0-10-20-0 % is applied.
- After confirmation of proper functionality, the actual Load cycle starts by applying 0 N(0%)and then gradually increasing the weight up to2570 N(100%).
- The deflection values should be recorded simultaneously.
- The central deflection is measured using LVDT.

Fig. 3. Test Rig For Bending Load Test

4. Results And Discussion

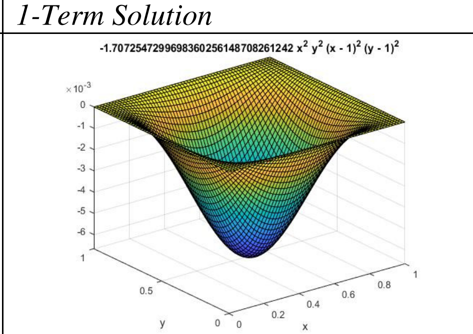
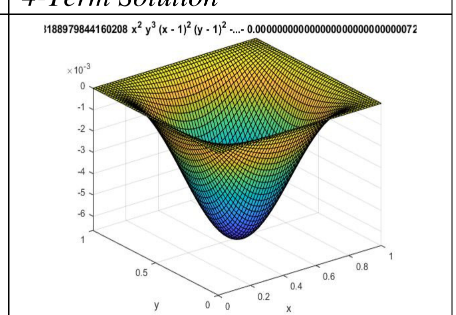
4.1. Analytical Solution Results

The symmetric laminate [0/90]s is analyzed using Raleigh Ritz 1-term and 4-term solution methods and results are shown in Table 2 by using CCCC boundary conditions. Table 1 shows the Raleigh Ritz approximations used and the results of Buckling load and deflection values.

Table 1. Raleigh Ritz Analytical Method Approximations

Result	*Layup-90*
Buckling load [N]	-49.5996
Transverse deflection of a point on the mid-plane [mm]	17.433

Table 2. Results Of 90^0 Laminate Using Raleigh Ritz Analytical Method.

Lay-up	*1-Term Solution*	*4-Term Solution*
[0/90]s		

4.2. Experimental results

The results obtained from 3-point bend test are listed in Table.3.

Table 3. Bend Load Test Results.

S.No.	*Load [N]*	*Average deflection [mm]*
1	0	0
2	257	4.3
3	514	5.9
4	771	6.8
5	1028	8.3
6	1285	9.9
7	1542	11.6
8	1799	13.1
9	2056	14.8
10	2319	17.2
11	2750	19.6

Table 4. Comparative Maximum Deformation Solutions For Carbon Epoxy Results

Name of the methodology	*4-Term solution (Raleigh Ritz method)*	*Experimental result*
Maximum deformation (mm)	17.43	19.60

It is observed the maximum deflection obtained from experimentation and Raleigh Ritz approximation technique 4-term solution are very closely matched. We understand that, as the number of coefficients increase, the accuracy of the solution reaches the Convergence point. Due to the computer restrictions and the methodology we used to write the code, we have restricted the solution up to 4-terms. So, we can consider that the written MATLAB code is optimum and can be used further for finding the deflection for various Layups for different composite materials. The material properties of considered composites are listed in Table 5. Comparison of the results of Maximum central deflection of CCCC boundary condition for various Layups for Carbon Epoxy, Glass Epoxy, Kevlar Epoxy, and Graphite Epoxy are shown in Tables. 6 and 7.

Table 5. Properties Of Various Composite Materials

S.No	*Property*	*Glass -Epoxy*	*Carbon – Epoxy*	*Kevlar– Epoxy*
1	Young's modulus in longitudinal direction, Es (GPa)	54	130	76
2	Young's modulus in transverse direction, Et (GPa)	18	5	5.5
3	Shear modulus, G_{st} (GPa)	9	5	2.1
4	Poisson's ratio,υ	0.25	0.24	0.34
5	Es/ E_t	3	26	13.81
6	G_{st}/E_t	0.5	1	0.38

Table.6 Maximum Deformation Of Laminates For Layups 45^0, 60^0, and 75^0

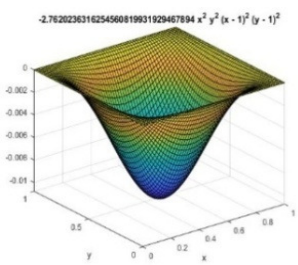
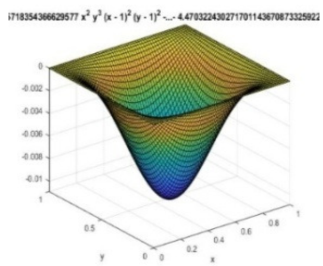
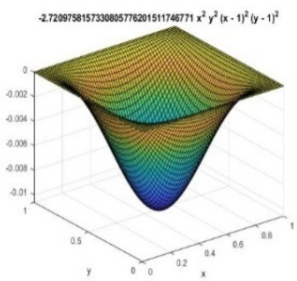
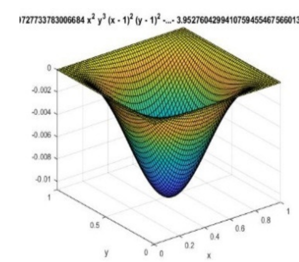
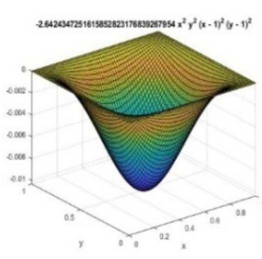
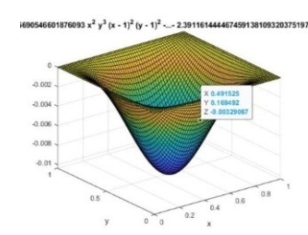
Layups	*1-Term Solution*	*4-Term Solution*
[45/-45]s		
[60/-60]s		
[75/-75]s		

Table 7. Maximum Deflection For Various Layups And Materials By Raleigh Ritz 4-Term Solution

S.No	*Lay-up [deg]*	*Maximum deflection (mm)*			
		Carbon-Epoxy	*Glass-Epoxy*	*Kevlar-Epoxy*	*Graphite-Epoxy*
1	45	18.73	48.6	34.23	12.41
2	60	18.39	48.1	33.62	12.16
3	75	17.74	46.7	32.43	11.46
4	90	17.43	46.4	31.86	11.42

5. Conclusion

The maximum central deflection for Carbon-Epoxy, the 12-Layer [0/90]s symmetric layup with CCCC boundary condition shown by analytical Rayleigh Ritz 4- term Approximation method through numerical analysis using Matlab and experimental are very close. As the written code is proved to be effective for the design of Symmetric Composite square plates of various dimensions and applied for other layups with different composite materials and observed that, the Carbon-Epoxy composite has minimum central deflection and it is better than other materials Glass Epoxy, Kevlar Epoxy, however, the Graphite Epoxy can give minimum deflection but due to cost factor that may not be preferred. Though all the materials can be replaced and used instead of metals due to their good strength-weight ratio, the selection of the material depends on our requirement for the design of the product. Though Carbon-Epoxy is a little costlier, it is the optimum material that can be used to design Composite panels in Aircraft that can face tough situations and have a high strength-weight ratio.

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