RES MILITARIS
REVUE EUROPEENNE D ETUDES EUROPEAN JOURNAL OF MILITARY STUDIES
Social Science Journal

INVESTIGATING VIBRATION AND BUCKLING CHARACTERISTICS OF COMPOSITE TWISTED PANELS UNDER HYGROTHERMAL CONDITIONS: RECENT FINDINGS

[1]Md.Abdul Muneer,[2]Bhukya.Suresh,[3]Lakavath.Mohan Babu,[4]Sravanaboina.Udaysri

[123]Assistant Professor,[4]Student

Department of Civil Engineering

Abdul Kalam Institute of Technological Sciences, Kothagudem,Telangana

ABSTRACT

The twisted composite cantilever has numerous uses in the aerospace and aviation industries as well as in civil, naval, and other high-performance engineering applications due to its light weight, high specific strength and stiffness, superior thermal characteristics, ease of fabrication, and other noteworthy specialties. Over the course of their service lives, these structural members will frequently be exposed to a wide range of service loads. The stiffness and strength of the structures may be considerably reduced by the environment's temperature and moisture content. Certain design criteria, such the structures' vibration and stability properties, might potentially be impacted by this. Determining the natural frequency and static stability of the composite laminated twisted cantilever panels under hygrothermal conditions is highly important. By doing this, you'll be able to avoid the typical problems that vibrations and stability cause. Considering this, the present analysis aims to investigate the stability and vibration behaviour of laminated composite twisted panels under hygrothermal conditions. A basic laminated model has been built in order to do a vibration and stability investigation on a laminated composite pre-twisted cantilever panel that has been exposed to hygrothermal conditions. A computer programme that is based on FEM and runs in the MATLAB environment has been developed to perform all of the necessary computations. Here, a hygrothermally loaded eight-noded isoparametric quadratic shell element is used, which is based on FSDT theory. Five degrees of freedom are present in each node, and the element has an isoparametric quadratic form. The element elastic stiffness matrices, mass matrices, geometric stiffness matrix pertaining to hygrothermal loads, and load vectors can all be computed using the concept of minimal potential energy. The effects of different elements including the number of laminate layers, aspect ratio, ply-orientation, geometry, and twist angle are investigated with respect to the vibration and buckling properties of laminated pre-twisted cantilever panels for a variety of temperatures and moisture concentrations. Numerical results are presented illustrating the effects of pre-twist angles, plate geometry, and lamination details on the vibration and buckling properties of twisted plates. This might be advantageous when creating composite twisted structures through customisation.

Composite twisted panel, hygrothermal loading, and stability are some of the keywords that might be used.

I.INTRODUCTION

Composite materials are being increasingly used in aeronautical and aerospace industry, civil, naval and other engineering applications due to their light weight, high-specific strength and stiffness, excellent thermal characteristics easy in fabrication and other important specialties. Structures used in the above fields are more often exposed to high temperature as well as moisture. The varying environmental conditions due to moisture absorption and temperature seem to have an adverse effect on the stiffness and strength of the structural composites. This wide range of practical applications demands a fundamental understanding of their vibrations and static characteristics of laminated composite shell in different temperature and moisture concentration.

1.1 Importance of Present Study

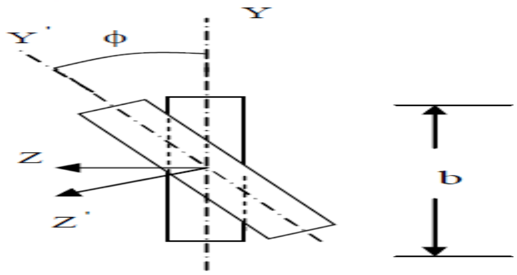
In a weight sensitive application such as aerospace industries are intensively involved in the development of advanced turbomachinery composite materials because of their excellent properties. Composites are usually subjected to changing environmental conditions during their service life. Among different environmental conditions structures are more often exposed to high temperature and moisture. The effect of temperature is known as thermal effect and the effect of moisture absorption from the atmosphere is known as hygroscopic effect. The combined effects of temperature and moisture are known as hygrothermal effect. The varying environmental condition due to moisture absorption and temperature seem to have an adverse effect on stiffness and strength of the twisted composites. Heat gets conducted into the laminate when subjected to rise in the temperature. The laminate consumes moisture when subjected to the moist conditions. The swelling or expansion is more across the fibres of the lamina. Hygrothermal effects induce a dimensional change in the lamina. But the properties of the constituents of the laminate is contrast, its free movement is inhibited. Thus, deformations and corresponding stress conditions are induced. The induced hygrothermal stresses is referred as residual stresses. As, the matrix is more vulnerable to the hygrothermal condition than the fiber, the deformation is examined to be more in the transverse direction of the composite material. The rise in hygrothermal conditions decreases the elastic moduli of the material and induces internal initial stresses, which may affect the stability as well as the safety of the structures. Hence, it is necessary to study and analyze the behavior such as buckling and natural frequencies of laminated composite twisted panels due to the hygrothermal effect seem to be an important consideration in composite analysis and design, which are of practical interest.

Composite materials are being increasingly used in automotive, marine and especially weight sensitive aerospace applications, primarily because of the large values of specific strength and these can be tailored through the variation of fibre orientation and stacking sequence to obtain an efficient design. The optimum design of laminated structures demands an effective analytical procedure. But the presence of various coupling stiffness's and hygrothermal loading complicates the problem of vibration and buckling analysis of twisted panels for obtaining a suitable theoretical solution. Even the real situation of boundaries in laminated structures is more complex because there are many types of boundary conditions that can be called simply- supported or clamped edges. So a clear understanding about vibration and buckling characteristics of the composite twisted panels is of great importance. A comprehensive analysis of the vibration problems of homogeneous turbo machinery blades, modelled as beams has been studied exhaustively. Some studies available on the untwisted plates subjected to hygrothermal loading and some studies are there on vibration aspects of laminated composite pre twisted cantilever panels. The vibration and buckling analysis of laminated composite pre twisted cantilever panels subjected to hygrothermal loading is current case of study. The problem involves different complicated effect such as geometry, especially non-developable doubly curved surfaces, boundary conditions with variable temperature and moisture concentrations. The above discussed aspects need attention and thus constitute a problem of current interest.

A thorough review of earlier works done in this field is an important requirement to reach the objective and scope of the present investigation.

II. REVIEW OF LITERATURE

The vast uses of conventional metals, its alloys and the ever increasing demand of composite materials in plates and shells are the subject of research for many years. Though the investigations is mainly focused on vibration and buckling of composite twisted panels subjected to hygrothermal loading, some relevant researches on vibration & buckling of composite plate subjected to hygrothermal loading are also studied for the sake of its



relevance and completeness. The literature reviewed in this chapter are grouped into two parts

- Twisted panels
- Composite plate

An excellent survey of the earlier works in the free vibration of turbomachinery blades was carried out by Rao [1973, 1977a, and 1980], Leissa [1980, 1981] for both stationary and rotating conditions. During the recent years, more rigorous methods of analysis have been developed based on the plate theory. Dokainish and Rawtani [2] investigated the natural frequencies and the mode shapes of a cantilevered plate mounted around a rotating disc. They considered the chord-wise bending effects, and obtain accurate results.

III. THEORY AND FORMULATON

The Basic Problem

This chapter presents the mathematical formulation for vibration and buckling analysis of the twisted plate. The basic configuration of the problem considered here is a composite laminated doubly curved twisted panel of sides 'a' and 'b' as shown in Figure.

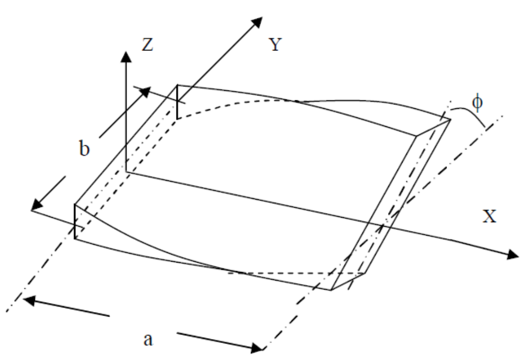
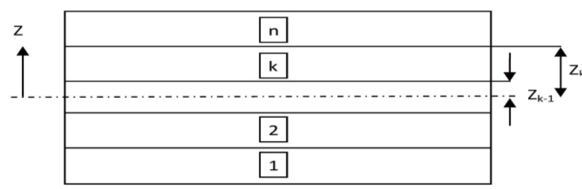


Fig. (a) Composite twisted panel

The twisted panel is modelled as a doubly curved panel with twisting curvature so that the analysis can be done for twisted plates, cylindrical and spherical configurations by changing the value of the curvature. The boundary conditions are taken to be that of a cantilever, that is fixed at the left end and free at the other edges. The basic composite twisted curved panel is considered to be composed of composite material laminates. 'n' denotes the number of layers of the laminated composite twisted panel.



(b) The lamination

Fig.1 Geometry of an N-layered laminate

Proposed Analysis

The governing equations for the vibration and buckling of laminated composite twisted Panels/shells subjected to in-plane loading are developed. The presence of external in-plane loads induces a stress field in the structure. This necessitates the determination of the stress field as a prerequisite to the solution of problems like vibration and buckling behaviour of pre twisted plates and shells. As the thickness of the structure is relatively smaller, the determination of the stress field reduces to the solution of a plane stress problem. The equation of motion represents a system of second order differential equations with periodic coefficients of the Mathieu-Hill type. The development of the regions of instability arises from Floquet's theory and the solution is obtained by Bolotin's approach using finite element method. The governing differential equations have been developed using the first order shear deformation theory (FSDT). The assumptions made in the analysis are given below.

Assumptions of the analysis

1) The analysis is linear with a few exceptions. This implies both linear constitutive relations (generalized Hooke's law for the material and linear kinematics) and small

displacement to accommodate small deformation theory.

2) The composite twisted panels are of various shapes with no initial imperfections. The considerations of imperfections are less important for dynamic loading.

3) The straight line that is perpendicular to the neutral surface before deformation remains straight but not normal after deformation (FSDT). The thickness of the composite twisted panel is small compared with the principal radii of curvature. Normal stress in the z-direction is neglected.

4) The loading considered is axial with a simple harmonic fluctuation with respect to time.

5) All damping effects are neglected.

Governing Equations

The governing differential equations, the strain energy due to loads, kinetic energy and formulation of the general dynamic problem are derived on the basis of the principle of potential energy and Lagrange's equation.

3.4.1 Governing Differential Equations

The equations of motion are obtained by taking a differential element of the twisted panel as shown in figure 2. This figure shows an element with internal forces like membrane forces N_x
N_y andN_{xy} , shearing forces(Q_x andQ_y) and the moment resultants(M_x , M_y and M_{xy}).

The governing differential equations for vibration of a shear deformable laminated composite plate in hygrothermal environment derived on the basis of first order shear deformation theory (FSDT) subjected to in-plane loads are (Chandrasekhar, Sahu and Dutta).

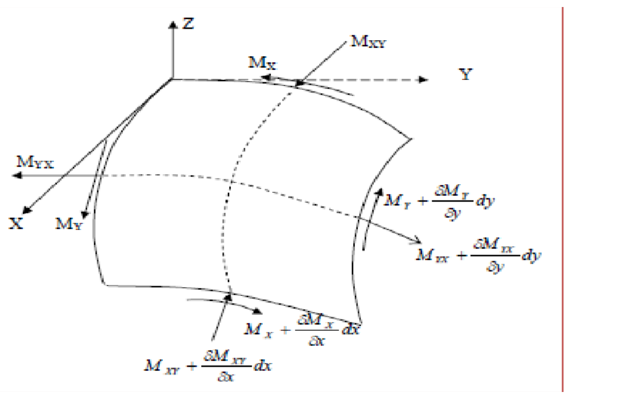
$$\frac{\partial Nx}{\partial x}+\frac{\partial Nxy}{\partial y}-\frac{1}{2}\left(\frac{1}{Ry}-\frac{1}{Rx}\right)\frac{\partial Mxy}{\partial y}+\frac{Qx}{Rx}+\frac{Qy}{Rxy}=P1\frac{\partial 2u}{\partial t}+P2\frac{\partial 2\theta x}{\partial t2}$$

$$\frac{\partial Nxy}{\partial x}+\frac{\partial Ny}{\partial y}+\frac{1}{2}\left(\frac{1}{Ry}-\frac{1}{Rx}\right)\frac{\partial Mxy}{\partial y}+\frac{Qy}{Rx}+\frac{Qx}{Rxy}=P1\frac{\partial 2v}{\partial t}+P2\frac{\partial 2\theta y}{\partial t2}$$

$$\frac{\partial Qx}{\partial x}+\frac{\partial Qy}{\partial y}-\frac{Nx}{Rx}-\frac{Ny}{Ry}-2\frac{Nxy}{Rxy}+Nx^{\circ}\frac{\partial 2w}{\partial y2}+Ny^{\circ}\,\partial 2w/\partial y2=P1\frac{\partial 2w}{\partial t2}$$

$$\frac{\partial Mx}{\partial x}+\frac{\partial Mxy}{\partial y}-Qx=P3\frac{\partial 2\theta x}{\partial t2}+P2\frac{\partial 2u}{\partial t2}$$

$$\frac{\partial Mxy}{\partial x}+\frac{\partial My}{\partial y}-Qx=P3\frac{\partial 2\theta y}{\partial t2}+P2\frac{\partial 2v}{\partial t2} \quad (1)$$



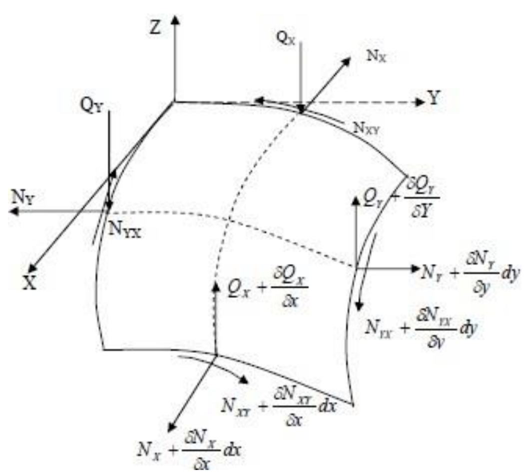


Figure 2: Force and moment resultants of the twisted panel

IV. RESULTS AND DISCUSSIONS

The composites plates/shells with

arbitrary geometries and boundary conditions subjected to hygrothermal loading got important roles to play as the structural elements in aerospace and other engineering structures. The plate and shell structures subjected to hygrothermal loading cause non-uniform stress field which greatly affects the stability and dynamic behavior of structures.

The present chapter deals with the results of the analysis of the vibration and buckling characteristics of homogeneous and laminated composite twisted cantilever panels subjected to hygrothermal loading using the formulation given in the previous chapter. As explained, the eight-node isoparametric quadratic shell element is used to develop the finite element procedure. The first order shear deformation theory is used to model the twisted panels considering the effects of transverse shear deformation. The vibration and buckling studies are carried out for laminated composite twisted panels subjected to hygrothermal loads to consider the effect of various parameters. The studies in this chapter are presented as follows:

- Convergence study
- Comparison with previous studies
- Numerical results

4.2. Boundary conditions

The clamped (C) boundary condition of the laminated composite twisted panel using the first order shear deformation theory is:

u = v = w = □ $_x$ = □ $_y$ = 0 at the left edge.

4.3. Vibration and buckling of twisted panels

- Convergence study
- Comparison with previous results
- Numerical results

4.3.1.Convergence study

The convergence study is done for non-dimensional frequencies of free vibration of cantilever square 4 layers symmetric cross ply and symmetric angle ply laminated composite plates for elevated temperature and moisture conditions for different mesh division as shown in Table 1 and table 2 for three angle of twist(ϕ =0º, 15º, 30º). The study is further extended to buckling analysis of laminated composite twisted cantilever plates subjected to hygrothermal condition as presented in Table 3 and 4 and this mesh is employed throughout free vibration, buckling and dynamic stability analysis of laminated composite plates in hygrothermal environment.

Table 1: Convergence of non-dimensional free vibration frequencies for cantilever twisted plate for different ply orientations at 325K temperature

a/b=1, a/t=25, At T=300K, E_1=130x10^9, E_2=9.5x10^9, G_{12}=6x10^9, $G_{13}=G_{12}$, $G_{23}=0.5G_{12}$

$\upsilon_{12}=0.3$, α_1=-0.3x10^{-6}/^{0}K, α_2 = 28.1x10^{-6}/^{0}K

Non-dimensional frequency, $\varpi=\omega_n a^2\sqrt{\frac{\rho}{E_2 t^2}}$

Mesh	Non-dimensional frequencies of free vibration for different angles of twist and ply orientation at 325K Temperature								
	0/90/90/0			45/-45/-45/45			30/-30/-30/30		
	0^0	15^0	30^0	0^0	15^0	30^0	0^0	15^0	30^0
4*4	0.8485	0.8303	0.7690	0.1596	0.1838	0.1166	0.5700	0.6130	0.5923
8*8	0.8484	0.8302	0.7689	0.1527	0.1782	0.1084	0.5664	0.6104	0.5901
10*10	0.8483	0.8302	0.7689	0.1517	0.1774	0.1072	0.5658	0.6100	0.5897

4.3.3. Numerical Results

After obtaining the convergence study and validating the formulation with the existing literature, the results for vibration and buckling studies for the twisted plate subjected to temperature and moisture are presented. The material properties used for the numerical study:

At T= 300 K, E_1=138x10^9, E_2=8.96x10^9, G_{12}=7.1x10^9, $G_{13}=G_{12}$, G23=0.5 G12

υ_{12}=0.3, α_1=-0.3x10^{-6}/^{0}K, α_2 = 28.1x10^{-6}/^{0}K, β_1=0, β_2=0.44

Vibration results for plate

For angle ply

The variation of non-dimensional frequency parameter Non-dimensional frequency,

$$\varpi=\omega_n a^2\sqrt{\frac{\rho}{E_2 t^2}}$$

for a eight layer laminated composite plate subjected to uniform distribution of temperature from 225K to 375K is shown in fig.5. With increase in temperature the frequency decreases for different twisted cantilever plates. As the temperature increases from 225K to 375K the decrease in non dimensional frequency for ply orientations 0⁰, 15⁰ and 30⁰ is about 16.18%, 25.3% and 69.86 %. respectively.

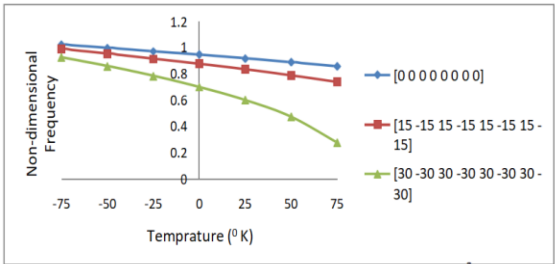


Fig 5: Effect of temperature on non-dimensional frequency for ϕ =30⁰ and for angle-ply laminated pre twisted cantilever plates (a /b=1, b/t=20)

The variation of non-dimensional frequency of vibration of pre twisted cantilever laminated anti symmetric angle ply plates with moisture is presented in figure 6. As the moisture concentration increases from 0% to 0.4%, the decrease in non-dimensional frequency is about 12.23% for 0⁰, about 16.02% for 15⁰ ply orientations and for 30⁰ ply orientations the % decrease in the non dimensional frequency due to increase in moisture concentration is about 47.58%.

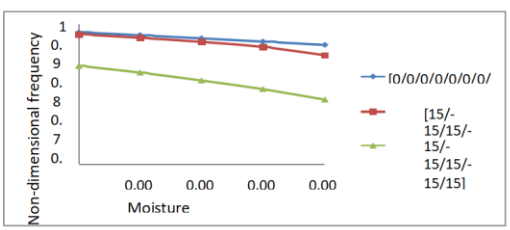


Fig 6: Effect of moisture on non-dimensional frequency for ϕ =30⁰ and for angle- ply laminated pre twisted cantilever plates (a /b=1, b/t=20)

V. CONCLUSION

In the present study the conventional finite element formulation is modified to study the free vibration and stability of laminated composite twisted cantilever panels subjected to hygrothermal conditions. An eight noded isoparametric shell element is used for this analysis with five degrees of freedom at each node. The formulation and program developed are general in nature and can handle non-uniform distributions of moisture and temperature. The numerical results for free vibration and buckling are presented and discussed above. The broad conclusion that can be made from this analysis is summarized below.

- The fundamental frequency decrease with increase in temperature and moisture concentration.
- For symmetric angle ply twisted cantilever panels as the temperature and moisture increases the frequency decreases with increase in ply orientation.
- It is found that as the angle of twist increases for a particular cross-ply orientation, the frequency parameter decreases. This is true for both the symmetric as well as antisymmetric cross-ply stacking sequences.
- For a particular ply orientation, the non dimensional frequency is less decreasing as the aspect ratio increases.
- The effect of temperature and moisture is much more in un-twisted plate than twisted plate.
- For twisted cantilever cross-ply laminates the percentage decrease in frequency is more for anti symmetric laminates than symmetric laminates.
- The critical load decrease with increase in temperature and moisture concentration.
- The buckling load of angle ply and cross-ply twisted cantilever panel decreases as the temperature and moisture concentration increases.
- The buckling loads tend to decrease with increase of lamination angle from 0° to 300 for untwisted and twisted plates.
- For all ply orientation, the non dimensional critical load is less decreasing as the aspect ratio increases.

From the above study, it is concluded that the vibration and buckling behaviour of the laminated composite twisted cantilever plates and shells are deeply influenced by the geometry, lamination parameter, angle of twist and hygrothermal condition. Therefore, the designer has to be cautious while dealing with structures subjected to hygrothermal loading. So, this can be used to the advantage of tailoring during design of composite twisted cantilever panels.

Scope for future work

The possible extensions to the present

study are presented below:

• The present investigation can be extended to dynamic stability studies of cantilever twisted panels subjected to hygrothermal loading.

• The twisted panels in this study are of uniform thickness and width. Hence the effect of varying thickness and width may also be incorporated in this study.

• Material non linearity can be taken into account for further studies of twisted cantilever panels.

• There is also a scope to study the vibration and buckling of twisted cantilever panels subjected to hygrothermal loading by experimental method.

REFERENCES

1. Ansari K. A., (1975), Nonlinear vibrations of a rotating pre twisted blade, computers and structures, 5, 101-118.

2. Barkai, M. and Rand, O., (1997), A refined nonlinear analysis of pre-twisted composite blades, Composite Structures, 39, (1-2), 39-54.

3. Barut A., Madenci E. and Tessler A., (2000), Nonlinear thermo elastic analysis of composite panels under non-uniform temperature distribution, International Journal of Solids and Structures, 37, 3681-3713.

4. Birman V, and Bert C. W., (1990), Dynamic stability of reinforced composite cylindrical shells in thermal fields, Journal of Sound and Vibration, 142(2), 183-190.

5. Bouazza M., Tounsi A., Benzair A. and Adda-bedia E. A., (2007), Effect of transverse cracking on stiffness reduction of hygrothermal aged cross-ply laminates, Materials and Design, 28, 1116–1123.

6. Chandiramani, K. N., Shete, C. D. and Librescu, I. L., (2003) Vibration of higherorder-shearable twisted rotating composite blades, International Journal of Mechanical Sciences, 45, 2017–2041.

7. Chazly N. M., (2005), Static and dynamic analysis of wind turbine blades using the finite element method, International Journal for Numerical Methods in Engineering, 36 (16), 2791-2804.

8. Chen c. L. and Chen L. W., (2001), Random vibration and reliability of a damped

thick rotating blade of generally orthotropic material, Composite Structures, 53, 365-377.

9. Chen L. W. and Chen Y.M., (1988), Vibrations of hygrothermal elastic composite plates, Engineering Fracture Mechanics, 31 (2), 209-220.

10. Cheng Z. Q. and Batra R. C., (2001), Thermal effects on laminated composite shells containing interfacial imperfections, Composite Structures, 52, 3-11.

11. Cheng Z. Q. And Batra R. C., (2001), Thermal effects on laminated composite shells containing interfacial imperfections, Composite Structures, 52, 3-11.

12. Cho, H. K., Optimization of dynamic behaviours of an orthotropic composite shell subjected to hygrothermal environment, Finite Elements in Analysis and Design, 45 (2009) 852 – 860.

13. Choi S. T. and Chou Y. T., (2001), Vibration analysis of elastically supported turbomachinery blades by the modified differential quadrature method, Journal of Sound and vibration 240(5), 937-953.

14. Choi, S. C., Park, J. S., Kim, J. H.,(2007) Vibration control of pre-twisted rotating composite thin-walled beams with piezoelectric fiber composites, Journal of Sound and Vibration, 300, 176–196.

15. Cook R. D., (1989), Concepts and applications of finite element analysis, John Wiley and Sons.

16. Dawe, D. J., Ge, Y. S., (2000), Thermal buckling of shear-deformable composite laminated plates by the spline finite strip method, Comput. Methods Appl. Mech. Engrg., 185,347-366.

17. Dawe, D. J., Yuan, W., Ge, Y.,(2005), Thermomechanical postbuckling of composite laminated plates by the spline finite strip method, Composite Structures, 71, 115–129.

18. Dokainish M. A. and Rawtani S., (2005), Vibration analysis of rotating cantilever plates, International Journal for Numerical Methods in Engineering,3 (2),233-248.

19. Farhadi S. and Hashemi S. H., (2011), Aeroelastic behavior of cantilevered rotating rectangular plates, International Journal of Mechanical Sciences, 53 (2011) 316–328.

20. Flaggs, D. L., Vinson, J.R, (1978), Hygrothermal effect on the buckling of laminated omposite plates, Fibre Science and Techonology, 11(5), 353-365.