Design of Ceramic Blade for Gas Turbine Application to Reduce Blade Flutter

Arun Jyoti Bhattacharjee
East Point College of Engineering and Technology
Bangalore, India

Manpuran Mandal
East Point College of Engineering and Technology
Bangalore, India

S. Kalyan Yadav
East Point College of Engineering and Technology
Bangalore, India

Abstract: Gas turbines during operation are subjected to high temperature and shock loads. As a result of which a number of vibrational phenomenon takes place throughout the turbine. Some of these phenomenon become so prominent that they damage the turbine and heavy losses are incurred. Once such phenomenon is the phenomenon of flutter. Flutter takes place on almost all types of steam and gas turbines. One of the most common areas which gets affected due to flutter is the aviation industry. Flutter affects the turbine section of an aero engine and damages its blades. However the use of ceramic can reduce the amount and magnitude of flutter taking place. In this paper we propose the use of alternate material such as ceramic that can significantly reduce the amount of flutter generated in the turbine blades. NACA 23012 has been taken as the test subject and numerical analysis is done to detect the flutter taking place in the engine blade. These results are compared with the results obtained by using silicon nitride as the material of choice. Also changes have been made in the aerofoil structure of the blade so as to keep the L/D ratio same. The results so obtained are in clear confirmation of the fact that if ceramic is used for the production of turbine blades the problem of flutter can be successfully solved.

Keywords: Turbine Blade, Ceramic, Flutter, Blade design

I. INTRODUCTION

Air transport has emerged as the primary medium of transporting people and goods from one destination to the other. The reason that the air transport or aviation industry is one of the most preferred means of transportation is that it saves a lot of time. And time being a major factor in determining performance in today's economy it is no surprise that aviation has become the primary means for transportation.

However along with the benefits also come the disadvantages. And like all other major scientific inventions an aircraft has its disadvantages too. Apart from the fact that air transport is not economic as compared to the other means of transportation a case study of the accidents that have occurred over the years of using aircraft as a means of transportation raises a major question: how safe is air transport? Unfortunately there are no clear answers to the. The fact also remains that no company engaged in manufacturing aircrafts would give a hundred percent guarantee that an aircraft which is manufactured by them would never be involved in an accident. In these circumstances we are left with but one option and that is to constantly carry out research in order to improve the various shortcomings involved with an aircraft and to make air transport safer day by day.

A major cause for the damage to the turbine section is by a vibrational phenomenon known as flutter. Flutter as it seems has been a predominant cause of blade damage and thus damage to the entire engine. Although a lot of research material is available that tends towards the detection and accurate prediction of flutter in the turbine and compressor blades very few effective techniques exist that can actually be called viable solutions to the problem.

II. LITERATURE SURVEY

A literature survey on the available research in the field of detection and elimination of blade flutter is done and the valuable material obtained from this survey has been taken as a reference to conduct further research in this field. D. G. Halliwell gives a brief description of the various types of flutter and their mechanism that affects the blades of a turbine along with a mathematical model that is capable of detecting frequency and mode shape of the flutter[1]. A.I. Sayma, M. Vahdati, J.S. Green & M. Imregun have created a mathematical model using 3D non-linear integrated aeroelasticity method[2]. Markus May, Yann Mauffrey, and Frederic Sicot suggested a time-linearized method based on small time-harmonic perturbations of the steady flow field[3]. A. V. Srinivasan has presented a practical study of the failures sustained by the turbine blades due to the flutter[4]. Dewey H. Hodges, Mayuresh J. Patil, and Seungmook Chae investigated the effect of thrust on flutter of a high aspect ratio wing[5]. Hiroaki Hasegawa, Yoshiaki Tsukamoto, Tadayuki Hanada and Katsuhiko Takita presents the results of the test performed on a turbine section made entirely of ceramic[6].

III. METHODOLOGY

When shockwaves hits the surface of a body the amount and magnitude of vibration generated depends largely on the material and structure of the body. We carried out our research in two phases. In the first phase the material of the body was altered and the second phase the shape.

The modern turbine blades inside an aero engine are made up of Nickel based alloys that are resistant to heat and can withstand long hours of pressure and temperature changes. However blade flutter occurs in these blades irrespective of the strength of these materials. So what we propose is to produce the same blade but made of ceramic. Ceramics have higher modulus of rigidity compared to the alloys and would thus serve to reduce blade flutter to a great degree. Also it would not change its ductility due to temperature variation over long hours of operation thus eliminating the need for the cooling mechanism.

However changing the material of the blade would change the aerodynamic properties of the material. As ceramic is lighter than the conventional alloy the lift force acting on the blade would be higher and the this could seriously affect the performance of the engine. Thus after successfully changing the material of the blade we would change the aerofoil shape of the blade to keep the lift by drag ratio of the blade same or nearly same to the original blade.

IV. TEST SUBJECT

For the purpose of Analysis NACA 23012 has been taken as the test subject. A few other values are also taken that correspond to commonly used turbine blades.
Fig 1 Shows the aerofoil shape of the blade under consideration.

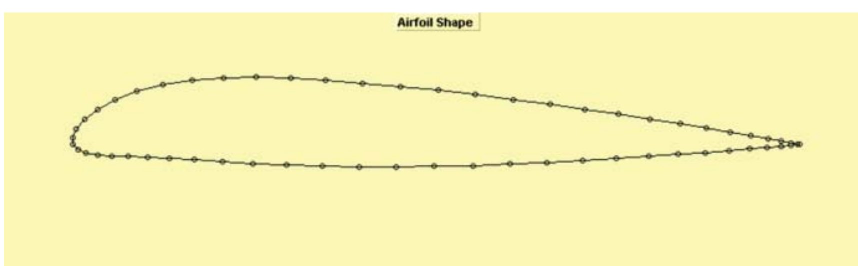

Fig. 1 Aerofoil Structure of NACA 23012

V. SPECIFICATIONS OF THE TEST SUBJECT:

1.Chord Length:	140 mm
2. Pitch:	105mm
3. Pitch to Chord Ratio:	0.75
4. Axial Chord Length:	83mm
5. Throat Width:	30mm
6. Gauging Angle:	74 degree

7. Inlet Flow Angle:	0 Degree
8. Lift Coefficient:	0.3
9. Location of Point of Maximum Camber:	15%
10. Reflex Camber:	0%
11. Maximum Thickness:	12%

Analysis

For the purpose of analysis model of the blade is created in JAVAFOIL. The coordinates of the aerofoil are then imported in CATIA and the model is prepared. The prepared model is then taken to ANSYS CFX for analysis. Two analytical models are prepared. One with the properties of EPM 102 which is the conventional material in use for the production of turbine blade and the other is Silicon Nitride which is a ceramic and the proposed material.

VI. RESULTS AND DISCUSSION

The models for the test subject along with the proposed blade model were analyzed in ANSYS CFX for the various boundary conditions that were applied. The results in the form of contour plot of the pressure variation on the surface of the blade have been used to determine the deformations that take place on the body of the blade. These deformations are a direct result of flatter and hence can be analytically used to understand the mechanics of the flutter taking place in the body of the blade. The mathematical model that has been found using the finite element method has also been used independently to determine the deformations taking place on the body of the blade.

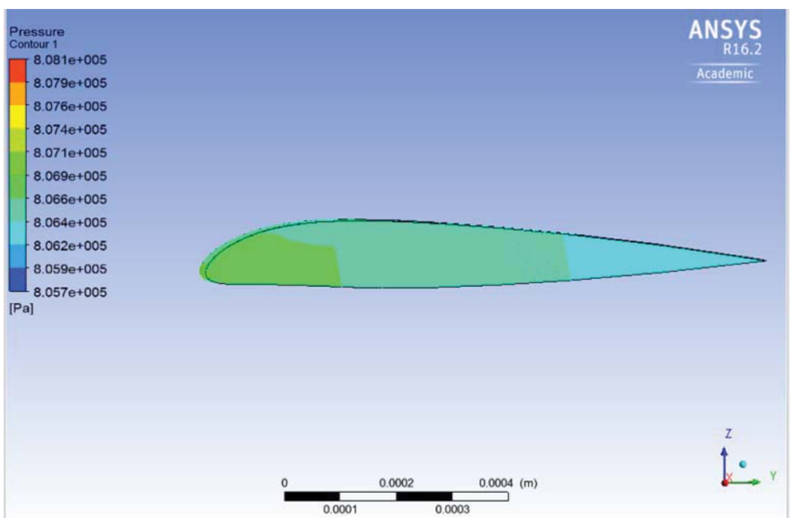

Fig. 2 Pressure Contour Plot of the Aerofoil Section

The pressure contour plot of the aerofoil section for the test subject blade is presented in fig. 15. The material of the blade as already mentioned is the super alloy EPM-102. As we go through the pressure contour plot of the aerofoil it can be clearly observed that the maximum pressure on the aerofoil is generated at the leading edge section of the aerofoil. The pressure generated at this section is 0.8069N/mm^2. As we proceed towards the trailing edge the pressure in the midsection of the blade decreases to 0.8064N/mm^2. And the pressure in the end section of the blade near the trailing edge is seen as 0.8062 N/mm^2.

Next we present the pressure contour plot of the pressure variations on the body of the blade. An analytical study of these results would yield the degree of flutter taking place in the blade as a result of the action of the flowing fluid.

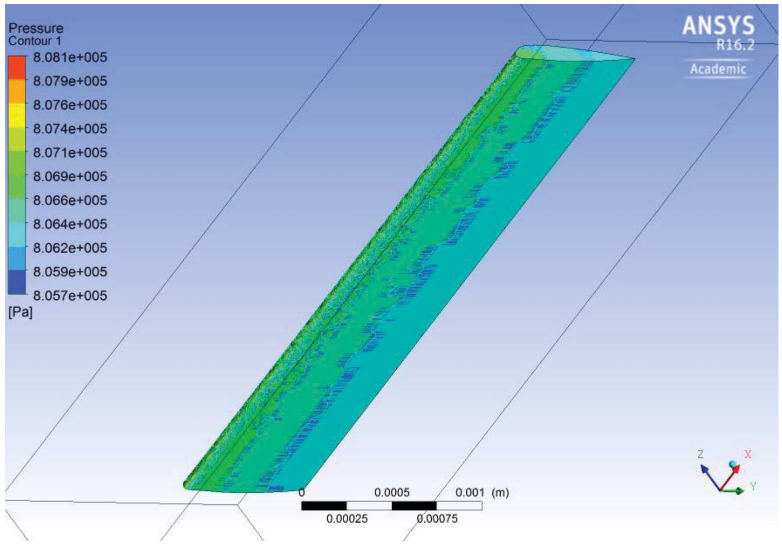

Fig. 3 Pressure Contour Plot of the complete Blade

The variation of pressure that is clearly visible in the midsection of the blade happens as a result of flutter taking place. Uniform pressure exists in the various sections of the blade whereas in the midsection discontinuous regions of high and low pressure can be clearly observed. Observations from the plot are taken and are used for the determination of the deformation caused by them.

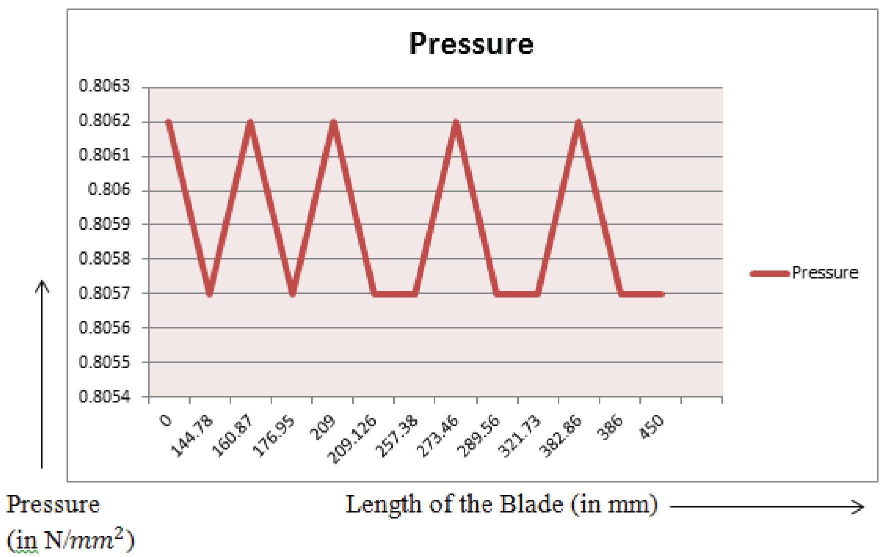

Fig.4. Plot for the Variation of Pressure along the length of the Blade

The variation of pressure along the entire length of the blade gives a fair idea about the nature of flutter vibrations taking place on the blade as a result of the fluid interactions taking place. Based on the values of the pressures at various locations on the blade surface we obtain the values of the deformations along the surface of the blade that happen as a result of the action of flutter.

Location (mm)	Deformation (10^{-7}) (mm)
144.78	2.86
160.87	3.185
193.04	3.822
209.126	4.14
273.47	5.414
321.73	6.37
347.4	6.87
450	8.91

Table1. Deformations occurring along the Blade surface

As we can observe from table 1 the values obtained from the mathematical model are in good agreement with those obtained from the analysis. Thus the analysis of the blade can be deemed to be accurate and has successfully predicted the behavior of blade flutter.

In the second phase of the analysis we analyze the proposed model of the blade. The results obtained from the analysis are in the form of pressure contour plot as given below:

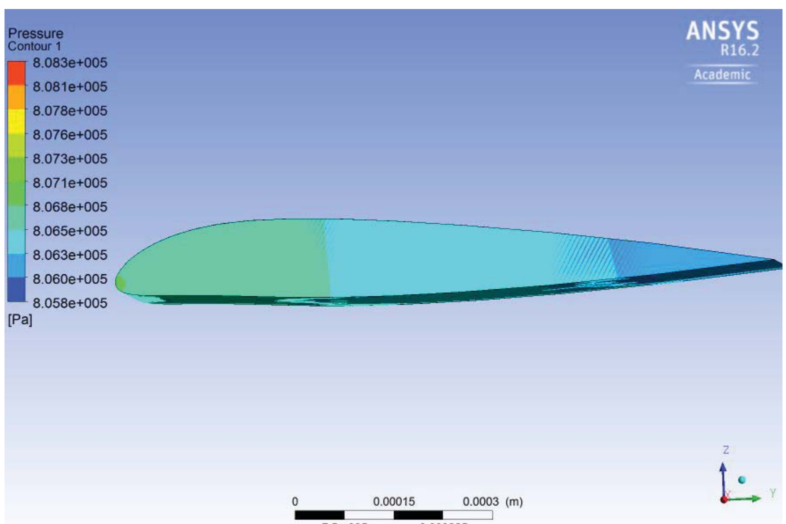

Fig. 5 Pressure Contour Plot of the Blade Aerofoil for Cearmic

The pressure contour plot for the aerofoil of the blade for ceramic material presents some interesting characteristics. Not only has the overall pressure distribution reduced when compared to the aerofoil section of the super alloy but the pressure gradient along the major chord of the blade has significantly reduced as well. The pressure in the leading edge of the blade is of the magnitude of 0.8065 N/mm^2. As we move towards the midsection of the blade it is observed that the pressure suddenly reduces to 0.8063 N/mm^2 and to 0.8060 N/mm^2 in the trailing edge section. Comparing these results with the results obtained from the analysis of the alloy blade where the pressure for the leading edge, midsection and trailing edge were 0.8069 N/mm^2, 0.8064 N/mm^2 and 0.8062 N/mm^2 respectively it can be clearly understood that the pressure distribution through the surface of the blade has reduced.

A study of the pressure contour plot for the entire surface of the ceramic blade is presented for the better understanding of the flutter taking place in the blade.

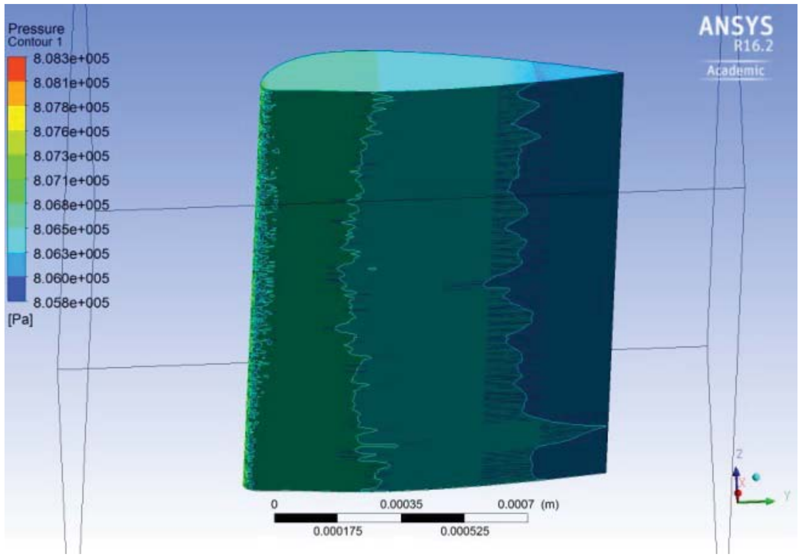

Fig. 6 Pressure Contour Plot for the Ceramic Blade Surface

On studying the blade surface we can see that only at two regions the fluctuation of pressure is observed. And also the difference of pressure in these regions is very small.

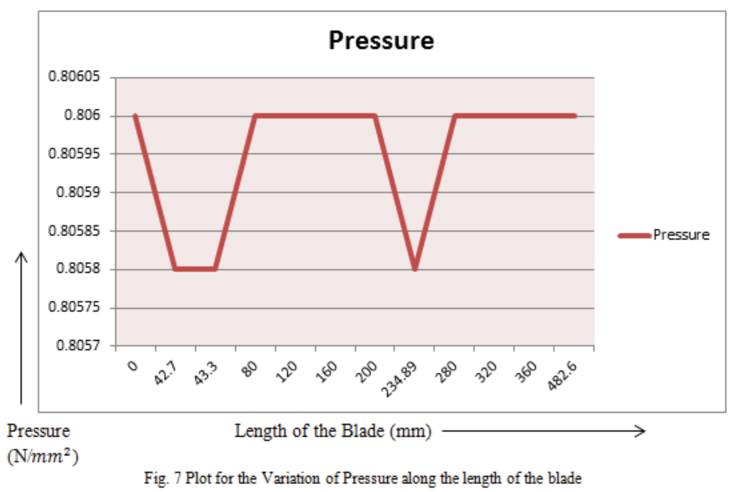

Fig. 7 Plot for the Variation of Pressure along the length of the blade

The pressure curve for the ceramic blade clearly shows that not only the magnitude of flutter has reduced but the places where flutter occur has also been reduced to only two regions as compared to multiple number of regions as is the case with alloy blade. However in order to understand the magnitude of flutter happening we obtain the displacements along the surface of the blade and compare them with those of the alloy blade.

Location (mm)	Deformation (10^{-8}) (mm)
42.7	8.456
234.89	9.357

Table 2. Deformations occurring along the Ceramic Blade surface

Observation of the data from table 2 clearly defines the effect of flutter in ceramic blade to be relatively less than that in the alloy blade. The deformation occurring in the alloy blade as a result of blade flutter is of the order of 10^{-7} whereas the deformation occurring in the ceramic blade as a result of flutter is of the order of 10^{-8}. Hence it is quite clear that ceramic when used a material for the manufacture of turbine blades can reduce blade flutter by a significant degree.

VII. DESIGN OF THE CERAMIC BLADE AEROFOIL

Changing the material of the blade is accompanied by a change in the L/D ratio or the Lift by Drag ratio of the blade. The lift by drag ratio is the most important parameter in deciding how the blade will function. A change in the L/D ratio can make the blade move either faster or slower. Either way it would affect the working of the turbine and in turn the compressor section of the engine. Such changes are undesired as it can affect the performance of the entire engine. Thus we need to keep the L/D ratio same as the test model or it should have a value quite near to it.

Lift by Drag ratio is the ratio of Lift and Drag forces working on the blade and they depend on the coefficients of lift and drag, density of the blade material, effective area of the blade and relative velocity of the blade to the fluid. All the other parameters are highly difficult to alter except the effective area of the blade. The effective area of the blade can be altered by changing the geometry of the blade and more specifically its aerofoil structure.

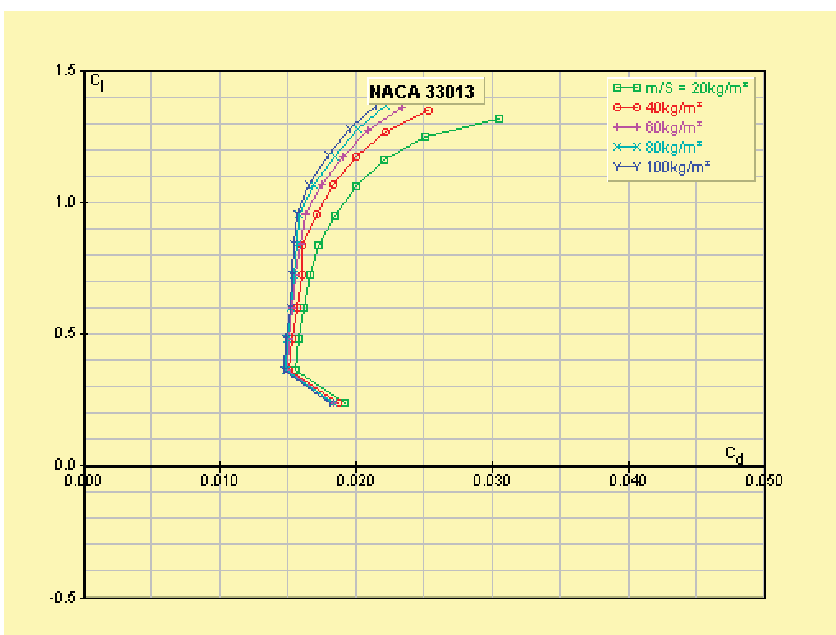

Fig. 8 Graph of L/D ratios for multiple densitites

With the help of JAVAFOIL we find that the L/D ratio of the turbine blade for aerofoil NACA 23012 for a density of 9.2gm/cm^3 is equal to 40.075 for a chord length of 180mm. We also find that the L/D ratio of the turbine blade for aerofoil NACA 23013 for a density of 3.21gm/cm^3 is 39.696 for a chord length of 180mm. Since the values of the L/D ratios are quite similar and close to each other the NACA 23013 aerofoil is chosen as the desired aerofoil for this particular application.

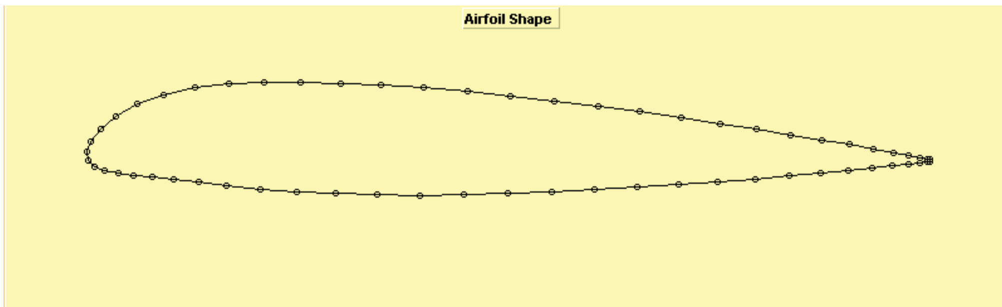

Fig. 9 Aerofoil NACA 23013

In the aerofoil all other parameters such as camber, coefficient of lift remains same except the thickness of the blade. The maximum thickness of the blade has been changed from 12% to 13%.

VIII. CONCLUSION

The research work carried out to determine the effect of using ceramic to reduce blade flutter has produced some quite remarkable and promising results. Initially it was expected that the magnitude of flutter would be reduced although the phenomenon would still be prominent. However since the magnitude of vibrations would be reduced it would be certainly helpful in avoiding the damages to the turbine rotor and in turn to the engine which usually occurs.

The most significant points that have emerged as a result of this analysis are:

1. The magnitude of the deformations that occur as a result of the flutter decreased when ceramic was used.
2. Number or regions of the occurrence of flutter was reduced to a bare minimum.
3. Overall pressure distribution and pressure gradient of the blade was reduced thus promising a longer operational life for the blade.
4. Since the temperature withstanding capability of ceramic is much higher than the conventional alloy the effect of temperature on the blade surface will be minimum thus eliminating the necessity of intercooling.

REFERENCES

[1] D. G. HALLIWEL (1971). Fan Supersonic Flutter: Prediction and Test Analysis. AERONAUTICAL RESEARCH COUNCIL REPORTS AND MEMORANDA

[2] A.I. Sayma, M. Vahdati, J.S. Green & M. Imregun (2001). Whole-assembly Flutter Analysis of a Low Pressure Turbine Blade.

[3] Markus May, Yann Mauffrey, and Fr´ed´eric Sico (2011). NUMERICAL FLUTTER ANALYSIS OF TURBOMACHINERY BLADINGS BASED ON TIME-LINEARIZED, TIME-SPECTRAL AND TIME-ACCURATE SIMULATIONS.

[4] A. V. Srinivasan (1997). FLUTTER AND RESONANT VIBRATION CHARACTERISTICS OF ENGINE BLADE. Presented at the International Gas Turbine & Aerwngine Congress & Exhibition Orlando, Florid.

[5] Dewey H. Hodges, Mayuresh J. Patil and Seungmook Chae (2002). EFFECT OF THRUST ON BENDING-TORSION FLUTTER OF WING. Journal of Aircraft vol. 39, no. 2, Mar.-Apr. 2002

[6] Hiroaki Hasegawa ,Yoshiaki Tsukamoto, Tadayuki Hanada and Katsuhiko Takita (2002). RESEARCH ON APPLICATION OF CERAMIC TURBINE TO JET ENGINE. ICAS 2002 CONGRESS.

[7] CARLOS A ESTRADA M (2007). NEW TECHNOLOGY USED IN GAS TURBINE BLADE MATERIALS. Scientia et Technica Año XIII, No 36. Universidad Tecnológica de Pereira

[8] He, L. 1992 Method of simulating unsteady turbomachinery flows with multiple perturbations. AIAA Journal, 30, 2730-273

[9] Marshall, J. G. & Imregun, M. 1996 , A survey of aeroelasticity methods with emphasis on turbomachinery, J. of Fluids and Structures, 10, 237-267

[10] Hirsch, C. 1995, Numerical computation of Internal and external
ows Vol- ume I, John Wiley & Sons.

[11] Vahdati, M. & Imregun, M. 1996 A Non-linear Integrated Aeroelasticity Analysis of a Fan Blade Using Unstructured Dynamic Meshes. Journal of Mech. Eng. Sci,Part C, 210, 549-563

[12] Vahdati, M., Morgan, K. and Peraire, J. 1993 The computations of viscous compressible flows using an upwind algorithm and unstructured meshes, Computational Non-linear Mechanics in Aerospace engineering, AIAA Progress in Aeronautics and Astronautics series.

[13] Baldwin, B. S. and Barth, J. 1991 , A one equation turbulence transport model for high Reynolds number wall-bounded
ows, AIAA Paper 91-0610.

[14] Erdos, J. I., Altzner. E. & McNally, W. 1977 Numerical solution of periodic transonic
ow through a fan stage. AIAA Journal, 15, 165-186

[15] Ewins, D. J. 1973 Vibration modes of bladed disk assemblies. I. Mech. E. J. of Mech. Eng. Sci. 15, 165-186

[16] Goldstein, M. E., Braun, W. & J. J. Adamczyk, J. J. 1977 Unsteady
ow in supersonic cascade with strong in-passage shocks, J. Fluid Mech. 83, 569- 604.