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Uncertainty Analysis of Hollow Airfoil Composite Structure by Using Finite Element Method

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Abstract :

This study represents simulation of Airfoil composite beam by using Monte Carlo method. A three dimensional static analysis of large displacement type has been carried out. Finite element analysis of NACA0012 airfoil composite structure has been carried out and uncertainty in Maximum Deflection is analyzed. Maximum Deflection was objective function. Chord length , beam length ,elastic modulus in XY,YZ,XZ and shear modulus of epoxy graphite in XY,YZ,XZ, ply angle and ply thickness of airfoil section, force are varied within effective range and their effect on Maximum Deflection has been analyzed. In order to validate the results, one loop of simulation is benchmarked from results in literature. Ultimately, best set of probabilistic design variable is proposed to reduce Maximum Deflection under static loading

Key words: -Hollow Airfoil composite structure, Monte Carlo Simulation condition

I. INTRODUCTION

Composite materials have found increasing use in aerospace and civil engineering construction. One of the common areas of application is panels and airfoils construction where composite materials with complex lay-ups are used. The following beam properties can be improved when composite materials are used: specific strength, specific stiffness, weight, and fatigue life. The thin-walled beams of open cross-sections are used extensively in space systems as space erectable booms installed on spacecraft; in aeronautical industry both as direct load-carrying members and as stiffener members. In addition, they are used as well in marine and civil engineering, whereas the I-beams, in the fabrication of flex beams of bearing less helicopter rotor [1]. Thin- walled structures are integral part of an aircraft [2]. That is the reason why many researchers consider it in their studies and published it in scholarly articles. Chan and his students focused on thin-walled beams with different cross-sections. Among their studies, Chan and Dermirhan [3] considered first a circular cross section thin walled composite beam. They developed a new and simple closed-form method to calculate its bending stiffness. Then, Lin and Chan [4] continued the work with an elliptical cross section thin-walled composite beam. Later, Syed and Chan [5] included hat-sectioned composite beams. And most recently, Rao and Chan [6] expanded the work to consider laminated tapered tubes. Ascione et al. [7] presented a method that formulates a one-dimensional kinematical model that is able to study the static behavior of fiber-reinforced polymer thin-walled beams. It's well known that the statics of composite beam is strongly influenced by shear deformability because of the low values of the elastic shear module. Such a feature cannot be analyzed by Vlasov's theory, which assumes that the shear strains are negligible along the middle line of the cross-section. Ferrero et al. [8] proposed that the stress field in thin-walled composite beams due to at twisting moment is not correctly modeled by classical analytical theories, so numerical modeling is essential. Therefore, they developed a method with a simple way of determining stress and stiffness in this type of structures where the constrained warping effect can be taken into account. They worked with both open and closed cross sections. Also, to check the validity of the method for structures made of composite materials, a beam with thin, composite walls were studied. Wu et al. [9] presented a procedure for analyzing the mechanical behavior of laminated thin-walled composite box beam under torsional load without external restraint. Some analyses have been formulated to analyzed composite box beam with varying levels of assumptions [10-13]. Therefore, analysis of airfoil beam under varying loading condition is key to improve the design and provide good agreement in results.

II. SIMULATION

The Monte Carlo Simulation method is the most common and traditional method for a probabilistic analysis. This method simulates how virtual components behave the way they are built. Present work uses FEM package ANSYS for analysis of composite beam of hollow NACA0012 airfoil shape. Element selected for meshing the geometry of the specimen is shell 181. Material properties of epoxy graphite are entered. Geometry of model is drawn in ANSYS software. Geometry is meshed by giving element size 1 mm. Mapped type of meshing is used. Meshed model of specimen is shown below in figure in 1.

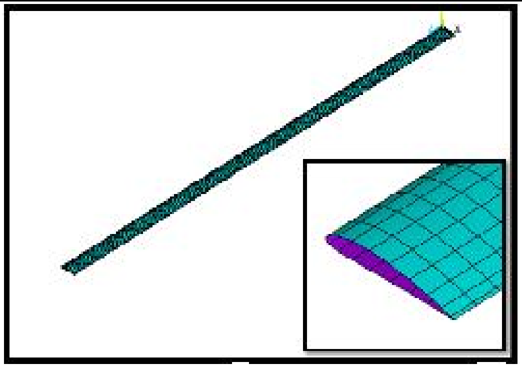

Figure 1: Meshed model of beamwith SHELL 181 elements (zoomed cross section in box)

Meshed model contains 3549 number of nodes and 3360 number of elements. The mesh size is reasonably small to obtain fairly accurate results. Figure 2 shows model with applied loads and boundary conditions. Geometry is meshed with element size 5 mm. Mapped type of meshing is used. Meshed model of specimen is shown in above figure

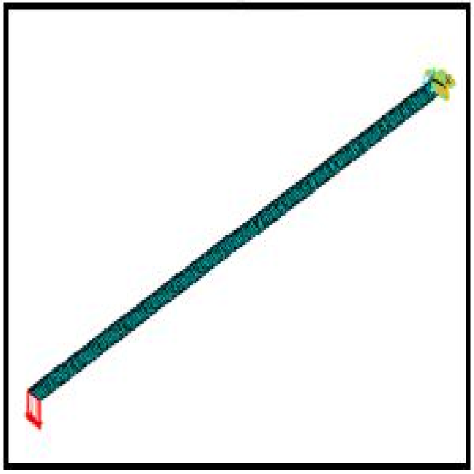

Figure 2: Meshed geometry with boundary conditions

III .RESULTS AND DISCUSSION

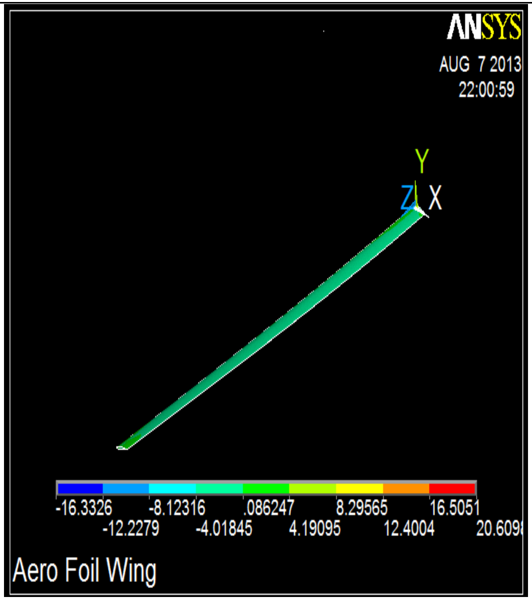

Figure 3: Contour plot of Maximum Deflection distribution

Figure 3 shows Maximum Deflection distribution in composite airfoil beam. Scatter plot is obtained at end of static analysis. Maximum value of Maximum Deflection is 20.609 N/mm^2 and it is observed in the region at the end of beam. One loop of simulation is validated from results in literature.

Table1: Comparison of Literature and ANSYS results [16]

Hollow Airfoil composite beam	**Maximum Deflection (N/mm^2)**		
	Literature	**Current study**	**% Error**
	18.93 N	20.609	11%

Probabilistic design system is used to determine the effect of one or more variables on the outcome of the Hollow Aerofoil composite beam. Present work considers:

- Geometric parameters: Length, Chord length.
- Material parameters: Young modulus, Poission ratio and Shear modulus in respective direction.
- Composite properties: Layer thickness and Orientation angles.
- Load parameters: Tip load.

Table 2: Parameters used in probabilistic design of NACA0012 hollow aerofoil beam [16]

Param-eter	**Distrib-ution Type**	**Mean (or Baseline)**	**Standard Deviation**
Length	Normal	1680 mm	16.80 mm
Chord length	Normal	56.0 mm	2.80 mm
EXX	Normal	142. x 10^3MPa	14200 MPa
EYY=EZZ	Normal	9.80 x 10^3 MPa	980 MPa
PRXY= PRXZ	Normal	0.42 MPa	0.084 MPa
PRYZ	Normal	0.50 MPa	0.10 MPa
GXY=GXZ	Normal	6 x 10^3 MPa	600 MPa
GYZ	Normal	4 x 10^3 MPa	400 MPa
Layer Thickness	Normal	0.127 mm	0.0127 mm
θ	Normal	60 deg.	6.0 deg.
Force	Normal	-1.0 N	0.1 N

All the parameters are considered as varying with Gaussian (or Normal) distribution (see Table 2). Using uncertainties as stated above, probabilistic design system is performed using ANSYS to know sensitivity of each parameter on Maximum Deflection. PDS within ANSYS uses Monte Carlo Simulation approach and analysis was looped through 1000 sample points considering the variations defined in the input variables and the corresponding static analysis of the output parameters.

This section presents results of probabilistic design system for Aerofoil composite beam. An overview of the data is provided by several plots from Figures 4 to 17. Figures 4 to 17 show Scatter plots each input and output parameters. Scatter plots show uncertainty in Maximum Deflection. Polynomial distribution of C1 powers is indicated by red colored line. As degree of polynomial distribution is small, there is more uncertainty in Maximum Deflection. If linear correlation coefficient of scatter plot is small then there is less uncertainty in Maximum Deflection and if larger then there is more uncertainty in Maximum Deflection. The same is true for rank order correlation coefficient.

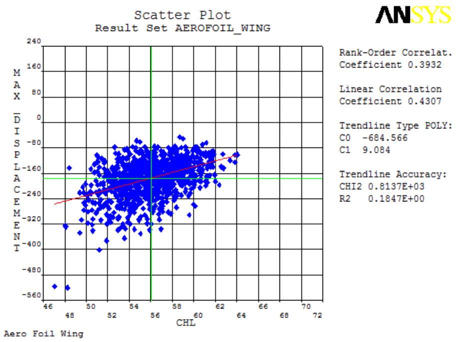

Figure 4: Scatter plot of Maximum Deflection vs Chord Length of hollow aerofoil composite beam

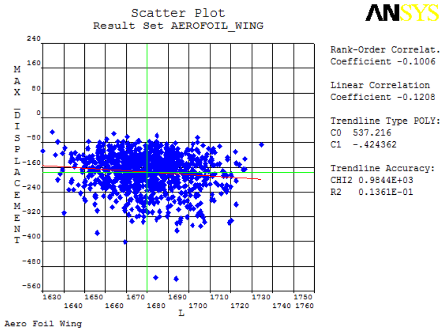

Figure 5: Scatter plot of Maximum Deflection vs Beam Length of hollow aerofoil composite beam

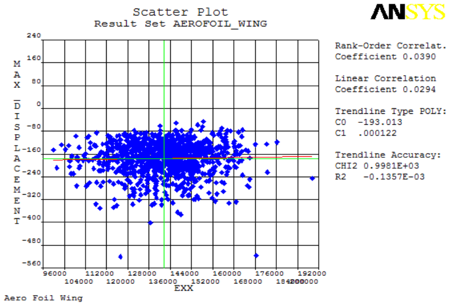

Figure 6: Scatter plot of Maximum Deflection vs EXX of hollow aerofoil composite beam

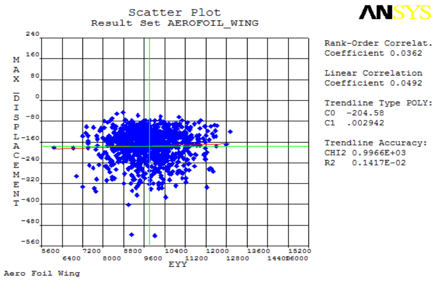

Figure 7: Scatter plot of Maximum Deflection vs EYY of hollow aerofoil composite beam

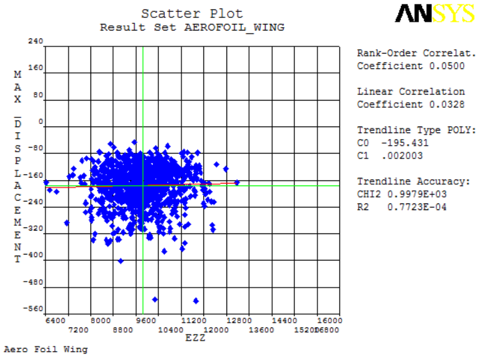

Figure 8: Scatter plot of Maximum Deflection vs EZZ of hollow aerofoil composite beam

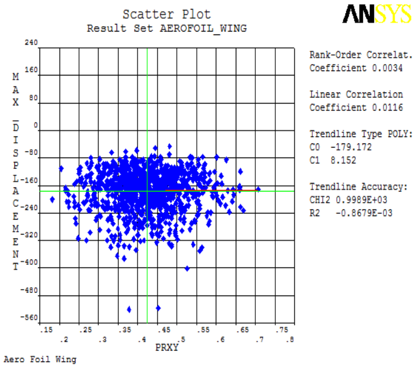

Figure 9: Scatter plot of Maximum Deflection vs PRXY of hollow aerofoil composite beam

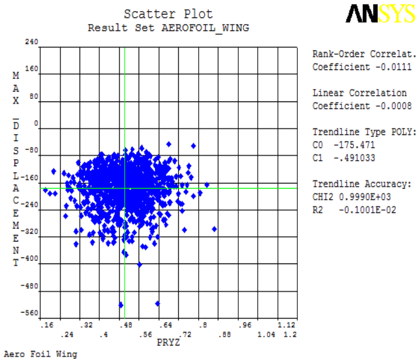

Figure 10: Scatter plot of Maximum Deflection vs PRYZ of hollow aerofoil composite beam

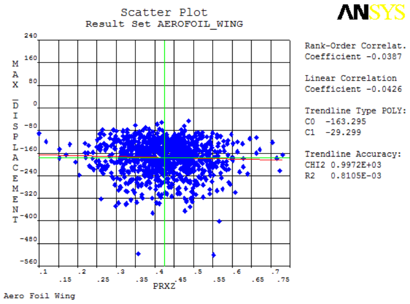

Figure 11: Scatter plot of Maximum Deflection vs PRXZ of hollow aerofoil composite beam

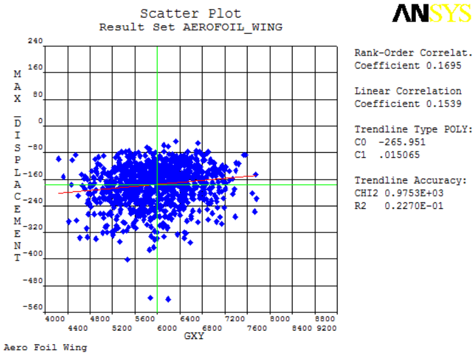

Figure 12: Scatter plot of Maximum Deflection vs GXY of hollow aerofoil composite beam

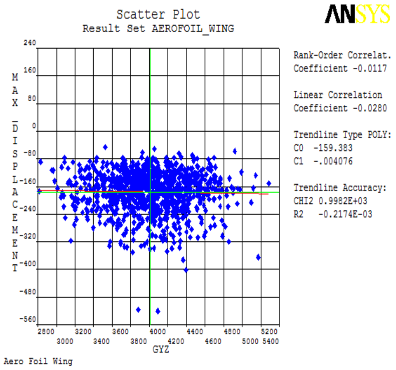

Figure 13: Scatter plot of Maximum Deflection vs GYZ of hollow aerofoil composite beam

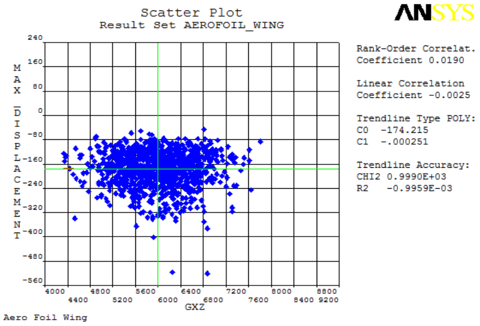

Figure 14: Scatter plot of Maximum Deflection vs GXZ of hollow aerofoil composite beam

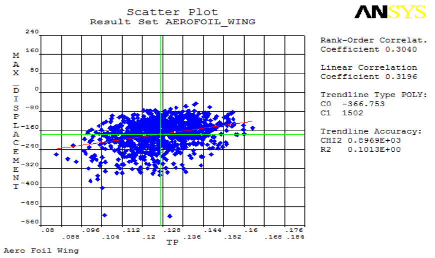

Figure 15: Scatter plot of Maximum Deflection vs Ply Thickness of hollow aerofoil composite beam

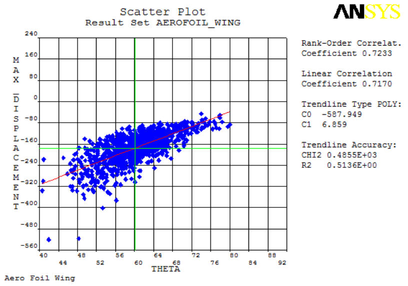

Figure 16: Scatter plot of Maximum Deflection vs Ply Angle (THETA) of hollow aerofoil composite beam

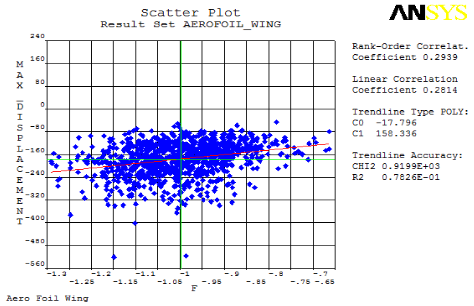

Figure 17: Scatter plot of Maximum Deflection vs Load of hollow aerofoil composite beam

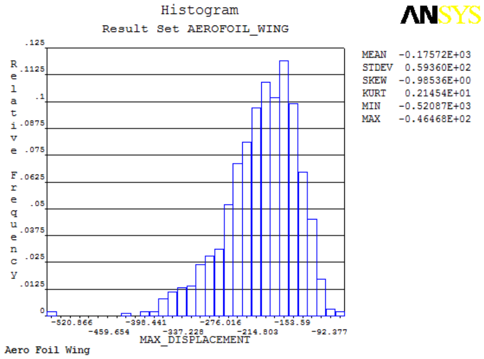

Figure 18: Histogram of output parameter Maximum Deflection of hollow aerofoil composite beam

Figure 18 shows variatiation in Maximum Deflection due to combined variation in various input parameters. deflection shows minimum 46.46 mm and maximum 520.57 mm.. Although all input parameters vary using normal distribution function but output parameters do not follow same. It can be seen from values of Kurtosis and Skewness. Value of skewness deviates from zero.

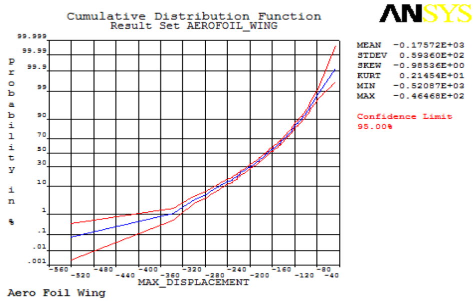

Figure 19: 95% confidence interval for Maximum Deflection of hollow aerofoil composite beam

Beams are typically designed to fulfill certain design criteria based on the output parameters. For example, a design or

Maximum Deflection is that the deflection will be above or below a certain limit. The cumulative distribution curve for deflection shows minimum 46.46 mm and maximum 520.57 mm. Probability of having deflection more than 175 mm is greater than 40% (see Fig. 19). The line in middle is the probability P that the maximum Maximum Deflection remains lower than a certain limit value with 95% confidence interval. The confidence interval quantifies the accuracy of the probability results. After the reliability of the beam has been quantified, it may happen that the resulting value is not sufficient. The answer to the question which input variables should be addressed to achieve a robust design and improve the quality; can be derived from probabilistic sensitivity diagrams plot.

Variation in follobeamsix parameters significantly affect deflection of aero foil beamwhereas variation in remaining eight parameters do not have significant effect:

- Orientation angle
- Chord length
- Ply thickness
- Tip load
- Shear modulus in XY
- Beam length

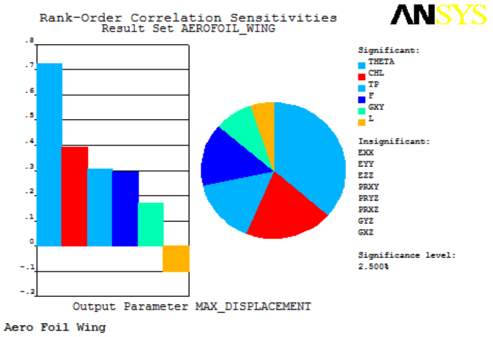

Figure 20: Sensitivity plot for Maximum Deflection of hollow areofoil composite beam for static analysis

IV. CONCLUSION

The influence of the design parameters on Maximum Deflection under variable loading condition is studied. The conclusions obtained are summarised as follows.

- Baseline analysis deflection results perfectly match with literature results for all three cases and percentage error is less than 3%.
- -Successfully carried out probabilistic analysis to study effect of input uncertainties on Maximum Deflection of static analysis for circular composite beam. From analysis it appears that not all input uncertainties affect Maximum Deflection.
- Co-relation coefficients and rank order coefficients of selected parameters are obtained to know the relationship between Maximum Deflection and design variables.

In Monte Carlo simulation, it was observed that maximum probable value of Maximum Deflection was shows minimum 46.46 mm and maximum 520.57 mm.

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