RESEARCH ARTICLE OPEN ACCESS

Probabilistic Design and Random Optimization of Airfoil Wing by Using Finite Element Method

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ABSTRACT: This study represents simulation ofAirfoil composite beam by using Monte Carlo method i.e.direct sampling. A three dimensional transient analysis of large displacement type has been carried out.Finite element analysis of NACA0012 airfoilcomposite structure has been carried out and uncertainty in bending stress is analyzed. More over optimization of selected design variables has been carried out by using random optimization method. Bending stress was objective function.Chord length , elastic modulus of epoxy graphite, ply angle of airfoil section, length , moment of inertia and forceare randomly varied within effective range and their effect on bending stress has been analyzed.In order to validate the results, one loop of simulation is benchmarked from results in literature. Ultimately, best set of optimized design variable is proposed to reduce bending stress under different loading condition.
Key words: -Airfoilwing, Monte Carlo Simulation, Random Optimization.

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 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 lesshelicopter 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 byVlasov'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 attwisting moment is not correctly modeled by classical analytical theories, so numerical modelingis 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 airfoilwing 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 hollowNACA0012 airfoilshape. FEM package ANSYS is used.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

1mm. Mapped type of meshing is used. Meshed model of specimen is shown below in figure in 1.

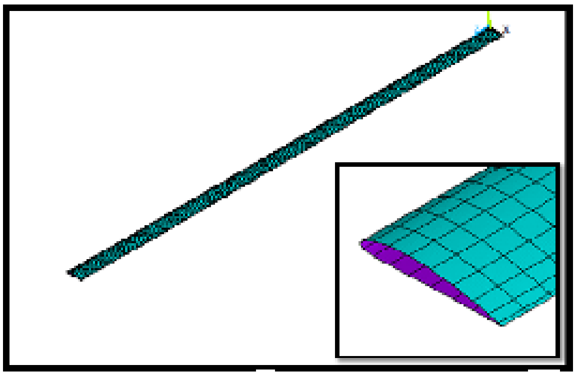

Fig.1Meshed model of wing with SHELL 181 elements (zoomed cross section in box)

Meshed model contains 3549 number of nodesand 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.

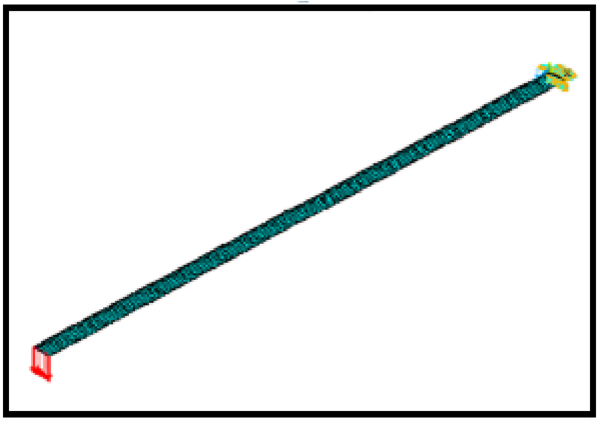

Fig.2 Meshed geometry with boundary conditions

Geometry is meshed with element size 5mm.Mapped type of meshing is used. Meshed model of specimen is shown in above figure 4.

Table 1. Random Input Variable Specifications

No.	Name	Type	Lower limit	Upper Limit
1	CHL	UNIF	20.000 mm	100.00 mm
2	EXX	UNIF	1×10^{05}(N/mm^2)	$2.\times10^{05}$ (N/mm^2)
3	TIME	UNIF	0.10000(Sec)	2.0000(Sec)
4	THETA	UNIF	10.000(Deg.)	90.000 (Deg.)
5	L	UNIF	1000.0 (mm)	3000.0(mm)
6	I	UNIF	10.000 (mm^4)	30.000 (mm^4)
7	F	UNIF	1(N)	50 (N)

CHL,Exx,THETA,L,I and D indicate chord length , elastic modulus of epoxy graphite, ply angle of airfoil section, length , moment of inertia and force respectively. These design parameters were varied by usign uniform distribution.Maximum bending stress in composite airfoilbeam is selected as response parameter. Properties of epoxy graphiteare entered.All degrees of freedom are made zero at one end of specimen while othe end is subjected to displacement.Range of displacement is selected in such a way that excessive distortion of the elements can be avoided.Loading conditions are varied. So, full Transient analysis of large dislacement type is executed in 4 steps . Each step is incremented by 1step.One simulation loop of transient analysis has been defined.It is executed1000 times by varing design parameters randomly within defined range.Scatter plot of maximum bending strees has been obtained at different combinations of selected parameters.Simillarly, Optimisation ofselected design parameters has been carried out inorder to reduce shape of composite airfoil beam. Random optimisation has been carried out.1000 feasible sets are obtained and the best set is seleted to reduce bending stress.

III .RESULTS AND DISCUSSION

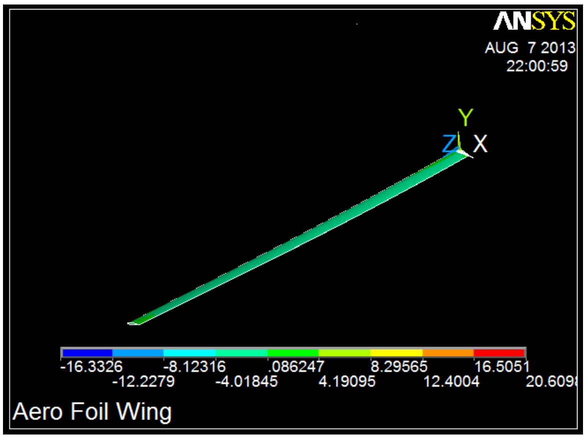

Fig.3 Contour plot of Bending stress distribution

Figure 3 shows bending stress distribution in composite airfoil beam. Scattered plot is obtained at 4th step of transient analysis. Maximum value of bending stress 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.

Table 2. Comparison of Literature and ANSYS results

	Bending stress (N/mm^2)		
	Literature	**Current study**	**% Error**
Airfoil wing	18.93 N	20.609	11%

Input variables were randomly varied with respect to output parameter bending stress. Scatter plots for the bending stress as a function of the most important random input variables are discussed as below.

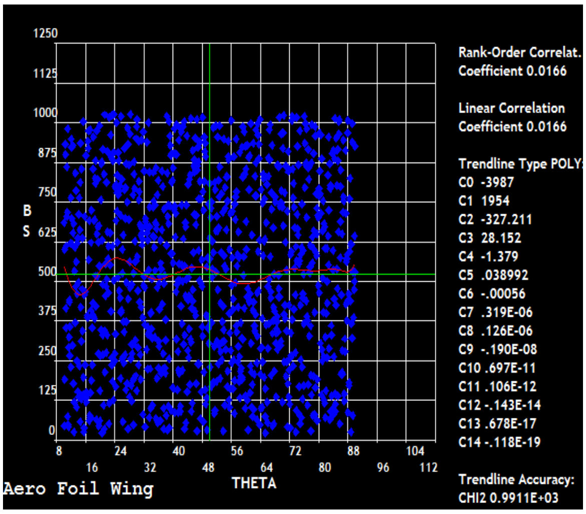

Fig.4Scattered plot of Bending stress vs.Airfoilply angle.

In figure 4, BS indicates probable value of bending stress with respect to Airfoil ply angle THETA in degree. Scattered plot shows uncertainty in bending stress. Polynomial distribution of C14 powers is indicated by red colored line. As degree of polynomial distribution is high, there is more uncertainty in bending stress It is observed that bending stress increased when ply angle THEA is within the range 16 deg. to 32 deg.Bending stress was reduced when THEA was within the range 8 deg. to 16 deg. It is observed that airfoilply angle is significant cause of uncertainty in bending stress because polynomial degree is more as compared to other design parameters.

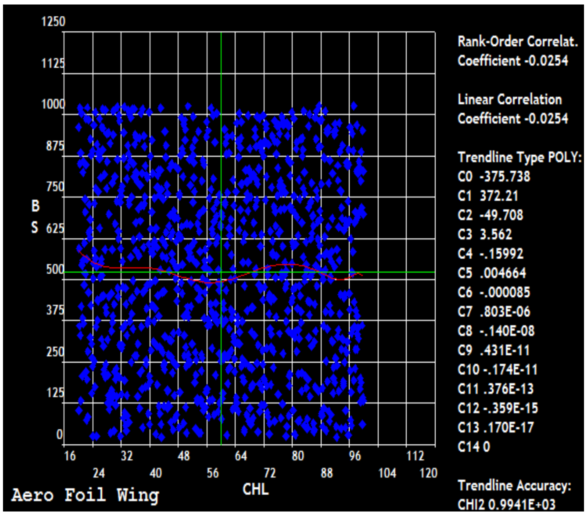

Fig.5 Scattered plot of Bendingstressvs.chord length of Airfoilsection.

It is obtained after 1000 samples (tests). Output parameter with combination of input parameters is plotted. Higher order Polynomial of 13 degree is used to plot scattering. It is observed that there is more scatter of bending stress from polynomial line within the thickness range 64mm -96 mm. BS = 5500 N/mm^2 which has rank 3 out of 1000 samples. The confidence bounds are evaluated with a confidence level of 95.000%.Figure 5 shows bending stress N/mm2vs.chord length of airfoilsection in mm. C0 to C13 indicates degree of polynomial. As degree of polynomial distribution is 13, there is more uncertainty in bending stress. As compared to ply angle THETA, uncertainty is less because degree of polynomial is less by one. Linear correlation coefficient between bending stress and chord length is 0.0254.Value of bending stress is obtained at different values of chord length. Value of bending stress at 96 mm chord length is around 1000 N/mm2. Particularly, above relationship between chord length and bending stress is obtained at varying loading conditions. There is considerable bending when chord length is randomly varied.It can be said that obtained bending stressdynamic bending strength. At the same time, bending stress is obtained at different combinations of geometrical and material parameters. At the chord length 97mm, bending stress is 976.98N/mm2. Figure 6 showsbending stress distribution of airfoilcomposite beam. Elastic modulus value is randomly varied within range1×10^{05} N/mm^2 to$2.\times10^{05}$ N/mm^{2}. Scattered plot is obtained at 4th step of transient analysis. Maximum value of bending stress is 965.76 N/mm^{2}.Rank order co-relation coefficient is 0.0006 and linear co-relation coefficient is 0.0007. It is observed that there is less uncertainty because maximum order of polynomial distribution of bending stress is of 5. As compared to chord length and ply angle THETA, random variation in elastic modulus does not cause uncertainty in bending stress.

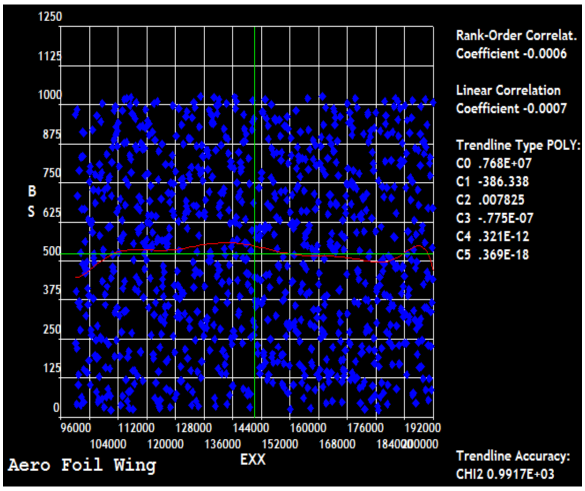

Fig.6 Scattered plot of Bending stress vs.elastic modulus

Figure 7 shows bending stress distribution of airfoilcomposite beam with respect to beam length. Beam length value is randomly varied within range 1000 mm to3000 mm. scattered plot is obtained at 4th step of transient analysis. Maximum value of bending

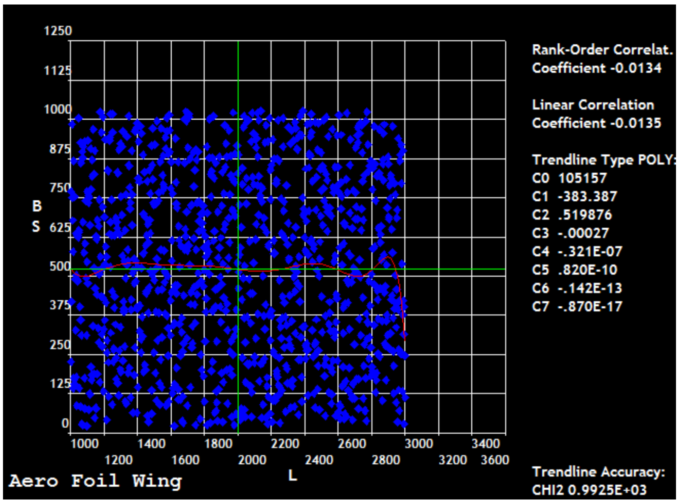

Fig.7 Scattered plot of bending stressvs. beam length

stress is 900.76 N/mm^{2}.Rank order co-relation coefficient is 0.0124.and linear co-relation coefficient is 0.0135. It is observed that there is less uncertainty as compared to chord length and ply angle THETA. Because maximum order of polynomial distribution of bending stress is of C 7.Nature of trend line shows that bending stress value is decreased after 2600mm beam length and it was approximately constant when beam length was 1800mm to 2400 mm. Also rank order coefficient value is less as compared to chord length and ply angle THETA.

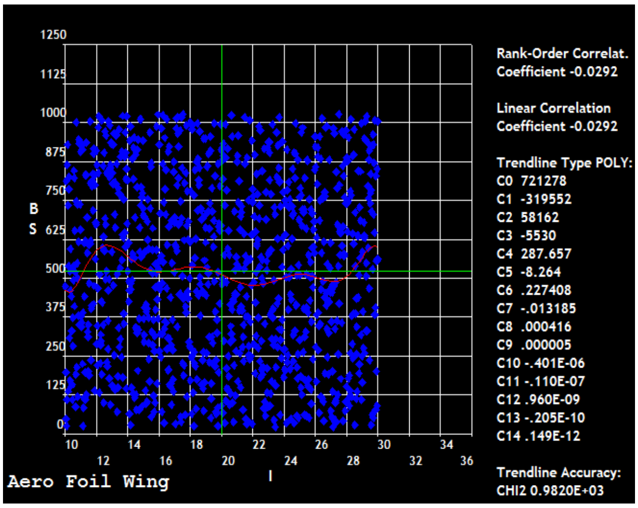

Fig.8 Scattered plot of bending stressvs.moment of inertia

Figure 8 showsbending stress distribution of airfoil composite beam with respect to moment of inertia. Moment of inertia value is randomly varied within range 10^4 mm to30^4 mm. scattered plot is obtained at 4th step of transient analysis. Maximum value of bending stress is 893.73 N/mm^{2}.Rank order co-relation coefficientlinear co-relation coefficients are same i.e. 0.0292. It is observed that there is more uncertainty as compared to chord length and ply angle THETA,because maximum order of polynomial distribution of bending stress is of C14. Also value of above coefficients is less as compared to CHL and THETA. Nature of trend line shows that bending stress value is increased within range 10 to 14 mm^4 moment of inertia.

After Monte Carlo simulation, results of optimization are discussed as below. Objective function was bending stress and design variables were same as that of Monte Carlo simulation.

Table 3 Design variables for random optimization of airfoil composite structure

Design Parameters	LowerLimit	Upper Limit
F	5 N	15 N
L	1000 mm	3000 mm
I	10 mm^4	30 mm^4
THETA	10 degree	90 degree
CHL	20 mm	100 mm
EXX	100e3 N/mm2	200e3 N/mm2
Objective function= BS (Bending stress) N/mm2		

1000 feasible sets of optimizations have been obtained and best set is proposed. Following figures show feasible of values of design variables with respect to objective function.

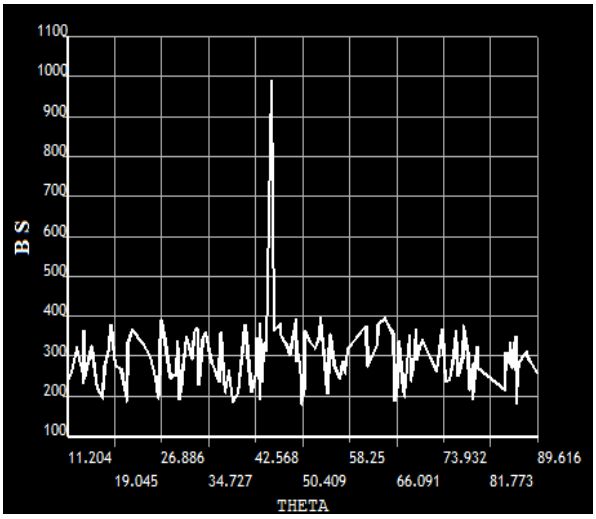

Fig.9 Feasible values of THETAvs.bending stress

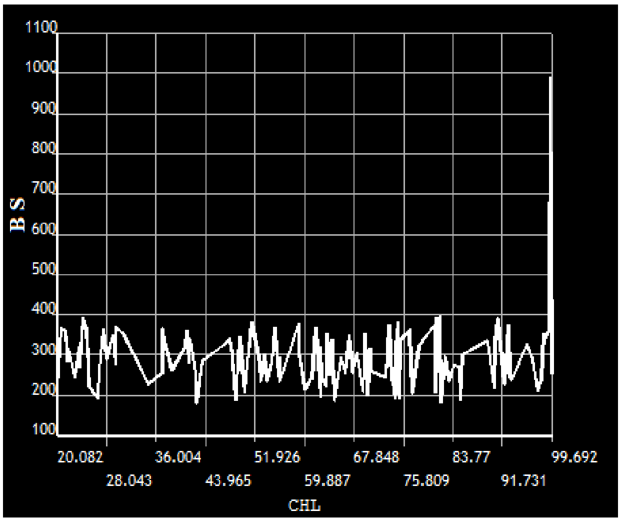

Fig.10 Feasible values of chord length vs. bending stress

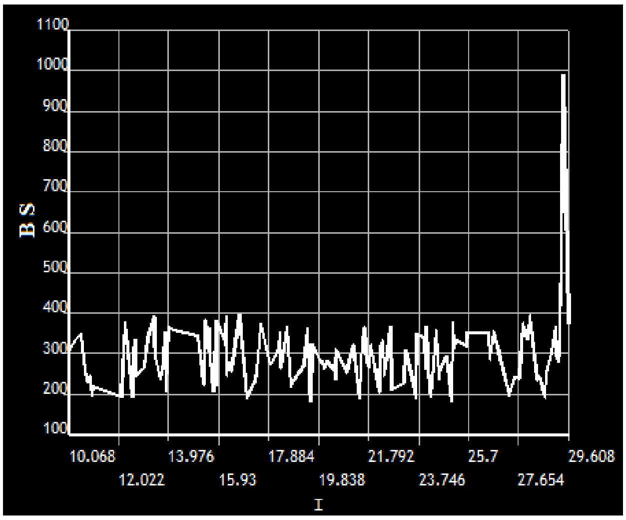

Fig.11 Feasible values of moment of inertia vs. bending stress

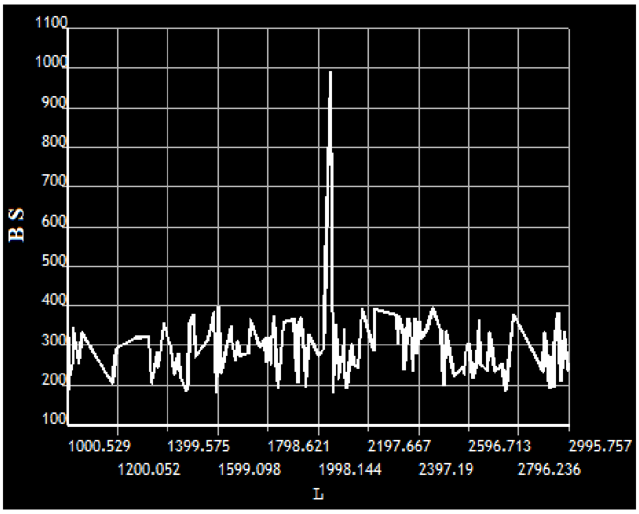

Fig.12Feasible values of beam length vs. bending stress

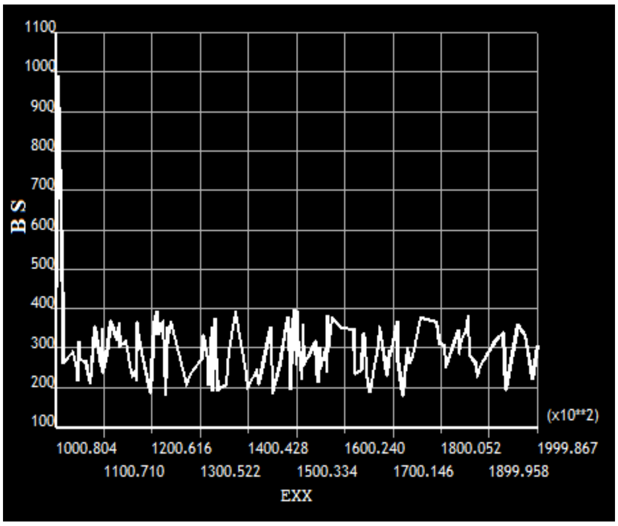

Fig.13 Feasible values of elastic modulus vs. bending stress

Table 4 shows best set among 1000 sets of feasible value of design variable of optimized design variables and reduced value of bending stress.

Table 4 Best set of randomoptimization

SET 742 (BEST OFFEASIBLE SETS)		
Design Variables	F	5.01 N
	L	1592 mm
	R	73.196 mm
	THETA	86.115 Degree
	EXX	122.85×10^{03}
	I	19.59 mm^4
	CHL	81.79 mm
Objective Function	BENDINGSTRESS	180.58 N/mm^2

IV CONCLUSION

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

-It is found that there is significant uncertainty in bending stress when chord length and airfoil ply angle are randomly varied

-Co-relation coefficients and rank order coefficients of selected parameters are obtained to know the relationship between bending stress and design variables.

-In Monte Carlo simulation, it was observed that probable value of bending stress was to 1131.79 N/mm^2. Bending stress value is reduced to 180.58 N/mm^2afterrandom optimization

-Best set of design variables has been proposed when airfoil wing is under varying loading condition.

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