OPTIMIZATION FOR COMPOSITE WING USING GENETIC ALGORITHM AND GRID TECHNOLOGY

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Abstract

One of particular advantage of the laminated composite is the ability to use the coupling effect of the unsymmetrical and unbalanced composite structure. The research is to analysis the coupling characteristic of unsymmetrical and unbalanced laminate and optimizes this structure for the wing aeroelasticity design. The Genetic Algorithm (GA) can solve the laminate optimization problem of the discontinuous variable and huge ply combination. A GA software system has been developed and used in an airplane vertical stability aero elastic laminate optimization.

1 Introduction

The application background is that a vertical stabilizer of an airplane with a large sweep angle has an inadequate stiffness. The big aeroelastic deformation in high altitude and high-speed situation has caused the inadequate direction stability of the airplane. The main object of the research is to satisfy with the direction stability of airplane by optimizing the composite panel of the vertical stabilizer using unbalanced and unsymmetrical composite laminate design.

The aircraft direction stability is needed to be increased 20% and the weight of vertical stabilizer skin is added not more than 20% to meet the design requirement.

One of particular advantage of the composite structure is ability to use the coupling effect of the unbalanced and unsymmetrical laminate design. The research project is to create an optimization tools to realize the aeroelastic tailor using the coupling characteristic.

The tasks of research project are:

- To optimize the laminate with the best angle and the best panel position. The unbalanced and unsymmetrical layer has been introduced in the vertical stabilizer composite panel design.
- To use the suitable tool, such as Genetic Algorithm, to optimization the laminate position problem that is discontinuing design variable and to get global optimization result.
- To use commercial FEM software tool to do the structure and aeroelastic analysis.
- To create the Grid System to reduce the calculation time during GA optimization analysis with huge genetic combinations.
- The goal of this research has been full filled after the aeroelastic tailor. The coupling effect of the unbalanced and unsymmetrical composite structure has been used to optimize the skin. A software system that integrate with GA software and FEM software into Grid System platform also has been created.

2 The coupling effect analysis for the unbalanced and unsymmetrical composite structure

The analyses have indicated that the coupling effect of the unbalanced and unsymmetrical composite is related with ply angle, sequence and laminate thickness distribution.

In the classical lamination theory, the constitutive equation of laminated composite is given by:

$$\begin{Bmatrix} N \\ M \end{Bmatrix} = \begin{bmatrix} A & B \\ B & D \end{bmatrix} \begin{Bmatrix} \varepsilon \\ k \end{Bmatrix} \qquad (1)$$

where A_{ij}, B_{ij} and D_{ij} (i,j=1,2,6),respectively represent the in-plane, coupling and out-of-plane stiffness components.

There is a relation between strains and loads forced in an unbalanced and unsymmetrical composite box structure.

$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_{xy} \\ k_x \\ k_y \\ k_{xy} \end{Bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{16} & b_{11} & b_{12} & b_{16} \\ a_{21} & a_{22} & a_{26} & b_{21} & b_{22} & b_{26} \\ a_{61} & a_{62} & a_{66} & b_{61} & b_{62} & b_{66} \\ b_{11} & b_{12} & b_{16} & d_{11} & d_{12} & d_{16} \\ b_{21} & b_{22} & b_{26} & d_{21} & d_{22} & d_{26} \\ b_{61} & b_{62} & b_{66} & d_{61} & d_{62} & d_{66} \end{bmatrix} \begin{bmatrix} N_x \\ N_y \\ N_{xy} \\ M_x \\ M_y \\ M_{xy} \end{bmatrix} \qquad (2)$$

k_{xy} is the twist ratio; that is the main guideline to weigh the coupling effect. When a moment M_X load was applied to the wing box, k_{xy} can be got as follow:

$$k_{xy} = d_{61} M_x \qquad (3)$$

The value of d_{61} determines the value of K_{xy}. The flexible matrix (d) of laminate can be wrote as :

$$d = (D - BA^{-1}B)^{-1} \qquad (4)$$

When a new lays were added on the normal laminate, the new laminate is changed into unsymmetrical and unbalanced one. From numerical calculation, we can get the relation between added ply angle and k_{xy}.

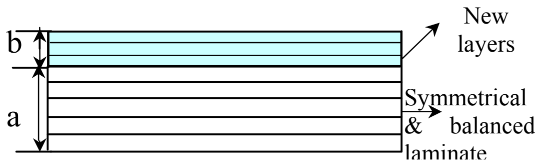

Fig. 1 Added composite skin laminate

Figure 2 has described the relationship between k_{xy} and lay angle θ in the two kind of laminate, that are laminates n=18 $[\theta/45/-45/0/-45/0/45/90/45/honey]_s$ and n=22 $[\theta/45/-45/0/-45/0/45/90/45/0/-45/honey]_s$ for composite panel with honeycombed sandwich box in bending loads. From the curve, we can see that there is a best angle for coupling effect for the wing structure. It is about 27° for T300/5208 material.

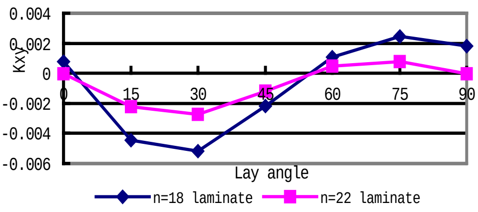

Fig. 2. The effect of added lay angle with the coupling effect k_{xy}

When the ply sequence has been changed, the coupling effect become different. The analysis of composite panel with honeycombed sandwich structure in bending load is shown that the ply sequence for the worst coupling effect is he laminate $[27/-45/45/0/0/45/45/-45/90/honey]_s$， the best one is：$[27/45/45/45/90/0/0/-45/-45/honey]_s$， the initial ply sequence is: $[27/45/-45/0/-45/0/45/90/45/honey]_s$.

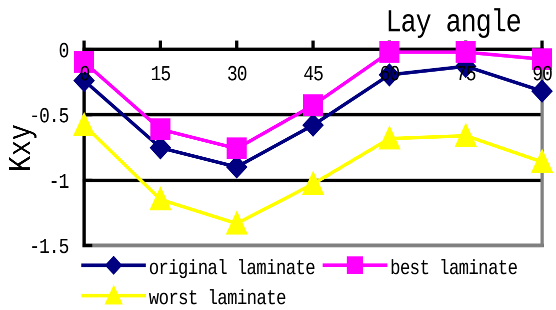

Fig. 3. K_{xy} values for different ply sequences

The results are shown that there is a right sequence and ply angle for each expected coupling effect.

3 To rich the goal of an aircraft direction stability by using GA optimization of composite material vertical stabilizer

The vertical stabilize with composite material skin FEM model has been created with part of fuselage. The skin has been divided into 332 FEM panels according to the structure. The vertical stabilize structure optimization is based on original designed skin by putting the new optimized layer on the best panel positions to form unsymmetrical and unbalanced laminate. From Figure2 and 3 it can be decided that the variables of structure optimum are the new lay added positions, the panel laminate sequence and the added new lay angle for the composite wing structure. The panel positions and the laminate sequence are the discontinue variables, so the common optimum method is difficult to solve this kind of problem. The Genetic Algorithm (GA) has the advantage to solve the problems for discontinue variable and huge ply combination. Another advantage for Genetic Algorithm is that it can be used to solve the optimization problem with complicated relation between design variable and objective function, because GA uses fitness objective function data as search information, in addition, GA simultaneously search from numerous points in all design possible range, thus it is apparent GA may locate a global optimization.

The GA has been used to optimize the coupling effect for the unbalanced and unsymmetrical composite structure to improve the direction stability coefficient ΔC_z in this research project. The basic equations for the composite vertical stability optimization are in the following:

Maximize： f(X) (objective function)

S t： $g_j(X) \le 0$ j=1… n （restrictions） (5)

$x_i^l \le x_i \le x_i^u$ i=1.2 （design variables）

$0^o \le x_1 \le 180^o$ (design lay angle variables)

$0 \le x_2 \le 332$ （design lay number）

The new lay panel positions are depended on the optimized panel number and the ΔCz sensitivity order of 332 panels when a new lay was added on each panel. For the optimization two objectives should be considered.

$$f(x)=[f_1(x), f_2(x)]^T \qquad (6)$$

Where $f_1(x)$ is the Δ Cz increment percentage, $f_2(x)$ is the weight increment percentage,

For this optimum problem, objective function $f_1(x)$ is the bigger the better, while objective function $f_2(x)$is the smaller the better, so this multi objective problem can be changed as single objective problem

Maximize ：$f(x)= f_1(x)/ f_2(x)$

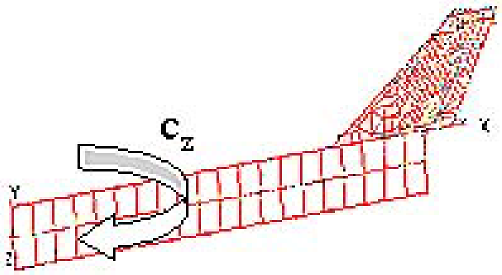

Fig. 4. An 851 nodes FEM analysis model

The 851 nodes FEM vertical stabilize model with fuselage has been established by using finite element software Msc/Patran and used to analysis aeroelastic character. The model of vertical stability skin has been divided into 332 panels. The composite skin was optimized by using GA tools which developed by the research, the objective functions are the direction invariability ΔCz of the model and the structure weight, the restrained functions are the skin thickness, design variables are the added layer thickness, the layer angle and the layer positions. Fitness equation and restrained functions were evaluated by using finite element software Msc/Nastran, so, genetic algorithms program has been compiled to integrate with analysis FEM software.

The analysis on sensitivity ΔCz with new layer positions, layer angles, layer panel numbers, has been done and the results has been shown in the following curves, when the skin weight has been increased 1%.

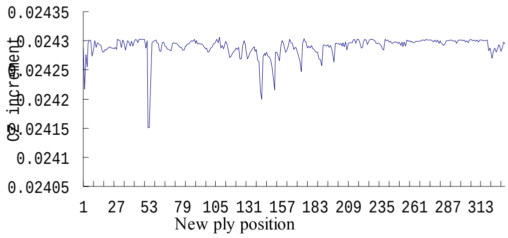

Fig. 5.The ΔCz sensitivity of the 332 skin panel positions

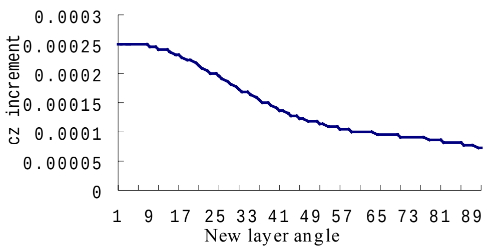

Fig.6. The ΔCz sensitivity of the layer angles

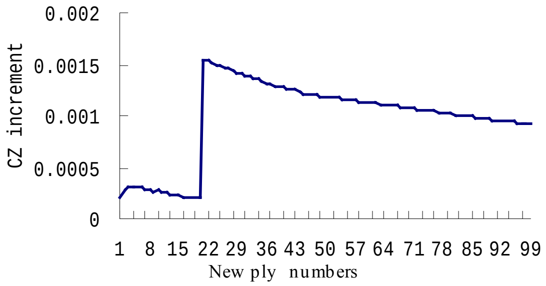

Fig.7. The Cz sensitivity of the added new layer panel number

The optimization is performed step by step. The skin weight is increased 1% in each step , GA is used to optimized the added layer angle, added layer numbers of each step until the final goal ΔCz is increased 20% finally, the skin weight is increased 22%.

The following points have been given by analysis the results:

Each panel position has different contribution to the ΔCz, the new layers should be added on the more sensitivity panel positions.

There is a best layer angle for each step optimization for new layer.

There is the best added new layer number for ΔCz contribution in the each step.

The sensitivity analysis has also been done by NASTRAN. The initial population of the analysis has been choosing as 200, the genetic generation was been choose as 30. The each NASTRAN analysis time is 15 seconds, the one step analysis time is 200*30*15/60=25hours. The 22 steps time is 550 hours, when the ΔCz has been reached 20%. The GA analysis steps are show in the following diagram.

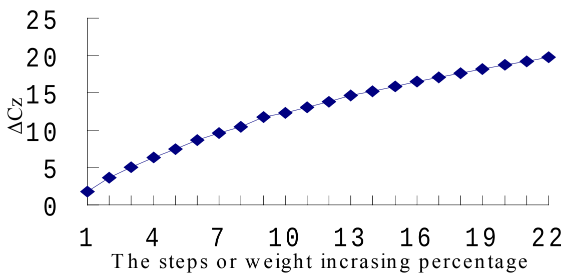

Fig.8. The relation between ΔCz and skin weight increasing percentage. (in each GA optimization step, 1% skin weight was increased)

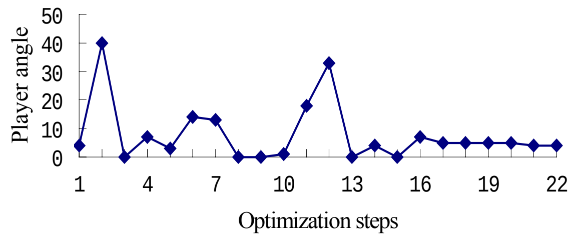

Fig.9. The relationship between the added new layer angles and optimization steps

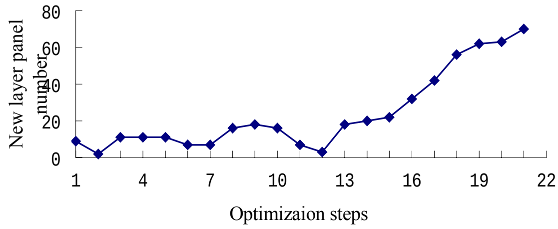

Fig.10. The relationship between new layer panel number and the optimization steps

The next steps are reducing some skin layer which is negative influence to ΔCz using GA analysis tools. The optimization result is 13% reduced and the ΔCz is keeping in 20%. The limitation for the optimization analysis is that the skin thickness should be not less than 1mm.

Finally, the GA analysis results reached the goal that is the ΔCz increased 20%. The skin weight is increased only 9%. The analysis result is shown in Fig 11.

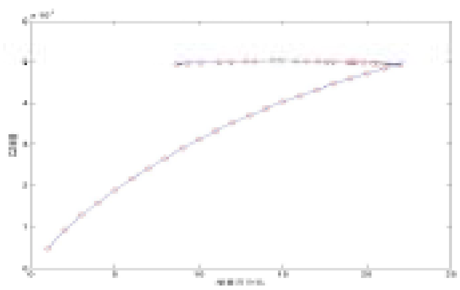

Fig.11. The relationship between weight and ΔCz during GA optimization

However, the weight is increasing 100% and the ΔCz is only increasing 15.6% if only entail skin thickness is doubled without using any optimal analysis. From analysis we can get the following results: The optimization is great help to the engineer for the wing aeroelastic design with lighter weight.

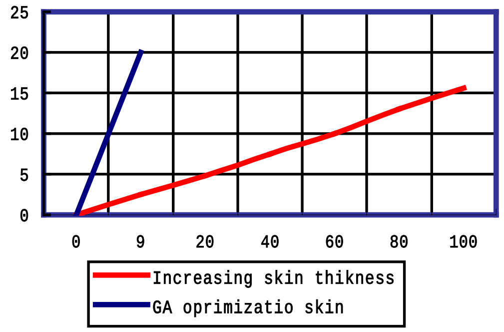

Fig.12. The optimization result compares with the result of doubled skin thickness

The skin lamination of the vertical stabilizer has been changed, when the skin added some layers and reduced some layers, after GA optimization. The change of the skin lamination was shown in the following figure 13~16.

The optimizing the skin composite laminate using unsymmetrical and unbalance laminate technology has satisfied with the stabilizer aerodynamic efficient and direction stability ΔCz, also the strength and the weight of the vertical stabilizer.

The optimum by the optimal system is reasonable, because the optimal calculation is performed step by step. In each step the sensitivity position panels of the skin has been chosen and added the layer with best angle. The positions of skin increasing layer and decreasing layers have been shown in figures 14, 15 that the distribution is meet the normal analysis result.

This structure optimum system can be used to solve many complex problems if the finite element model can be established.

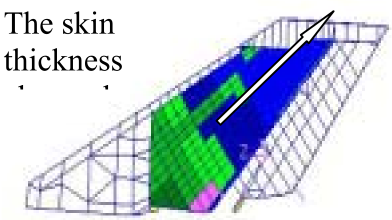

Fig.13. The vertical stability skin thickness distribution and the FEM model

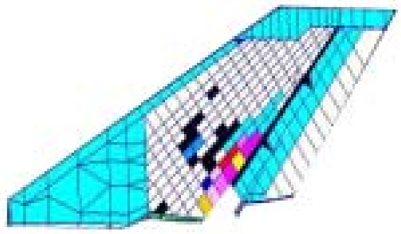

Fig.14. The new increasing layers distribution in 22% weight increasing

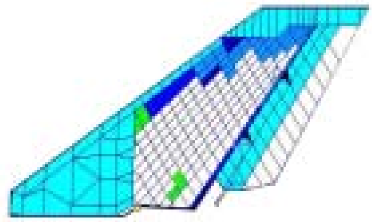

Fig.15. The reduced skin thickness distribution after GA optimization.

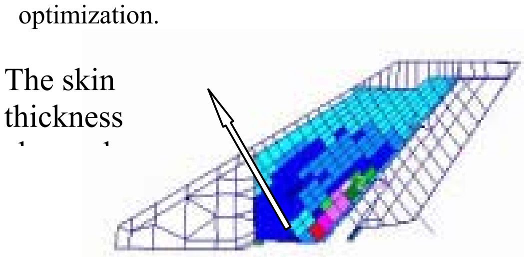

Fig.16. The optimized skin thickness distribution

The problem for GA optimization is taking too much time for analysis. It has taken 550 hours to do the vertical stabilizer GA optimization calculation in a good PC computer in this research. For large-scale structure GA optimum by using finite element analysis and vast scale objective function computing of the project, the analysis time can be several weeks. Engineer does not accept the long analysis time.

The Grid technology can solve the long analysis time problem in the GA optimization by paralleled computation using more computer resource to get time saving.

4. Using Grid technology to great reduce the GA optimization time

There is a strong requirement to solve the computation time and can be accepted by engineer. The grid technology in GA programs has adopted in the research work and a grid system hardware with 5-computers has been established to reduce the optimization calculation time. In situation of the grid system, using Platform Company software tools, the genetic algorithm analysis can be reduced from 550 hours to 120 hours. The time can be future reduced if there is more computer resource. The hardware structure is shown in the following figure.

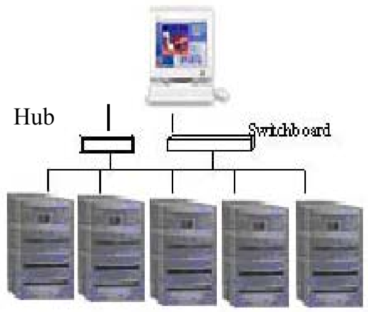

Fig.17. The Grid system hardware structure

The software system structure is consisted of the GA optimization model, the grid model, the FEM analysis models and user interface. The grid model is Platform Company product "Job Schedule-LSF". The system architecture is shown in the fig 18.

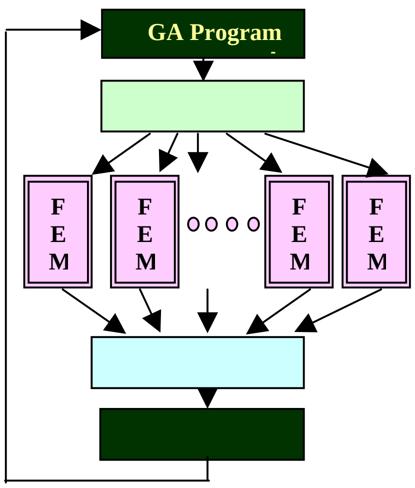

Fig. 18. The grid platform architecture for the GA optimization system

When the Grid compute system is adopted, the GA program needed to be divided into the independent run module. The function of 'GA Program A' is to initialize the genetic population import data. The function of 'GA Program B' is to execute the genetic operators. Grid computer environment is good to be used for share the computation resource.

The advantage for the grid system "Job Schedule" is that the 5 hardware resource can be shared to run the GA optimization and the FEM programs automatically. The grid system also can create the operation floor, and provide the operation information during computation. Compared with conventional parallel computation for fitness evaluation, grid technology has some advantage. The grid system is designed to allow the execution of computation intense programs under a heterogeneous set of computers, using 100% all the available CPUs resource. So, we can use our PC intranet for our computing. When a computer is idle or cannot be using its full resources, the Grid system will take a part of re-allotted task; returns computing end results and commence on a new working process.

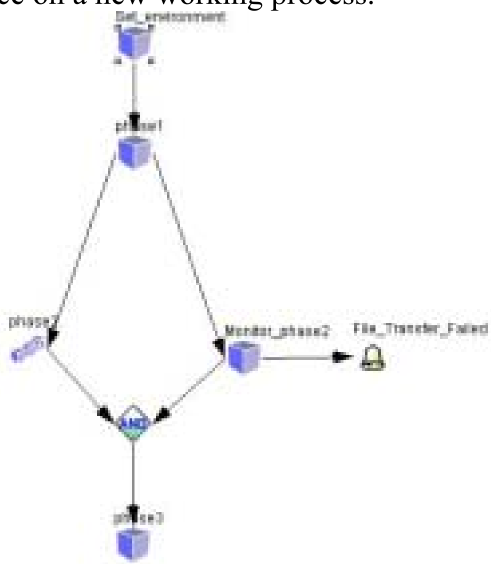

Fig.19. The job flop of the grid system

In fig19. The function of set environment module is to initialize all the parameters, such as the number of population, generations, executing program path, the function of 'Phase1' is to generate initial populations, the function of 'Phase2' is to parallel computing the finite element modules, the function of 'monitor_phase2' module is to monitor all compute machines to see if the compute result was returned, if the result did not return exceed some time, the system send out the ring to give an alarm. Namely,' File_ transfer_ failed' module and the function of 'phase3' module are to carry out the gene operation.

The system has running the analysis of the optimization vertical stabilizer lamination design and the results is fully agreed with before analysis results and reduce almost 5 times computation time.

5 Conclusion

This research has reach the final goal and has the conclusion:

- The unsymmetrical and unbalance laminate technology will improve the wing earoelastic design.
- The GA optimization tools can solve the topologic and discontinue variable optimization problem and can get global optimization.
- The Grid technology can great reduce the computation time by share resource.
- The new skin layers should be re-laminated by using stiffness equivalent method. (Not mentioned in this paper)
- The time could be further reducing if using knowledge management technology.

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