Inspection - Hole Shape Optimization of a Lower Wing Panel Based on Geomatric Boundary Shapes

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Abstract

Most structural design optimization jobs deal with finding the optimum size of structural components. Non-linear mathematical programming techniques are normally used to optimize this sort of problems. Some problems need not only optimum component size but also optimum shapes. Change of shape can be dictated by shape basis vectors, which define grid coordinate changes. As change of shape relates directly to change of geometry, the rules of geometric variation need to be set up which in this case is the variation of geometric boundary shapes. Change of boundary shape will alter the overall shape of the continuum. With the rule of geometric shape change been set-up, the optimization is carried out employing non-linear mathematical programming optimization. This paper presents an optimization of an inspection holes of IPTN CN-235 lower wing panel. It is required to have an optimum shape of the inspection hole and the dimensions of surrounding components. The wing itself was loaded by its critical design cases. Shape basis vectors were defined through geometric boundary shapes. Optimization was performed using MSC NASTRAN optimization design software.

Keywords: *shape optimization, wing structure, inspection hole*

INTRODUCTION

Design is an iterative process involving synthesis and analysis. Synthesis is related to creation of structure and includes selection of structural types, configuration, type of components, and determination of component dimensions. Analysis relates to determination of structural responses such as stresses, strains, and deflections, under external loads. These responses must be within some predetermined allowable ranges, which are stated in the structural design requirements. For large and complex structures, analysis normally is performed using the finite element method. In aircraft structures, optimum design normally is a least weight design, which still meets their design requirements.

Most structural design optimization jobs deal with finding the optimum size of structural components. Non-linear mathematical programming techniques are normally used to optimize this sort of problems [1,2,4,5]. The constrained optimization problems are dealt with Penalty Methods or Feasible Direction Techniques, combined with appropriate search strategies such as Steepest Descent, Powel, or Quasi-Newton methods [1,4,5]. One dimensional search can be done by interpolation methods or Golden Section algorithm [1,5].

However, certain structural design problems allow more freedom in defining (and even require) not only optimum component size but also in finding optimum shapes. The later problem can be found in cases such as design of propeller blades, shape of dams, or finding optimum shape of aircraft wing inspection holes. Change of shape is dictated by shape basis vectors, which define grid coordinate changes. As change in shape directly relates to the change in geometry, there is a need to specify a rule of geometric variation, which in this case is the geometric boundary shapes. In turn, the variation setting will determine the shape basis vectors. Change of boundary shape will alter the overall shape of the continuum. With the rule of geometric shape change specified, the optimization is carried out employing non-linear mathematical programming optimization as mentioned previously.

As the structural analysis is performed using finite element method, the change of continuum shape requires remeshing of the finite element model of the continuum, which shows the need of automatic meshing capability. This paper presents an optimization of an inspection hole of IPTN CN-235 lower wing panel. It was required to have an optimum shape of the inspection hole and the dimensions of surrounding components. The skin was modelled as membrane element, while the stringers and flanges were modelled as axial bar elements. The wing itself was loaded by its critical design cases. In solving this problem, shape basis vectors were defined through geometric boundary shapes. Optimization was performed using MSC NASTRAN optimization design software [3], which is also equipped with a finite element analysis tool. NASTRAN optimizer uses an optimization strategy derived from the Feasible Direction Method.

BASIS VECTORS AND ANALYTIC BOUNDARY SHAPES

Shape basis vectors were used to describe the properties of allowable shape changes [3]. Given the design criteria, the optimizer then determines the best linear combination of these vectors. The concept of basis vectors will be illustrated in the following case of cantilever shape optimization.

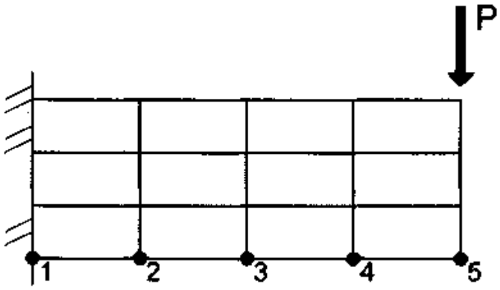


Figure 1: A simple 2D cantilever

Figure 1 shows a simple 2D cantilever which is loaded at the cantilever tip. The linear distribution of bending moment (as well as constant shear) indicates a possible optimum shape cantilever design with a larger height at root, as shown in Figure 2.

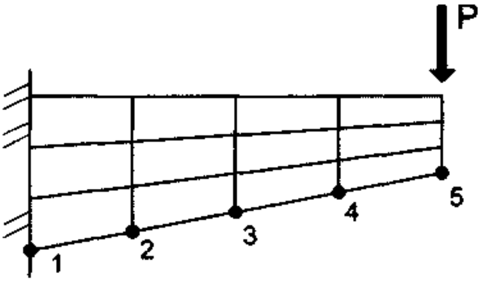


Figure 2: Optimum shape cantilever

The above optimum shape can be achieved by allowing the lower surface (or lower line in 2D case) to change in its length and orientation while maintaining linear profile. In order to simplify the problem, it is further assumed that the height of cantilever at root is fixed. As such, a pre analysis is needed to make sure that it is indeed safe to hold the root height at its initial value. From observation, it can be seen that position of grid-1 remains fixed and grid-5 changes by moving upward. The other grids (2 to 4) will move in a linear manners. The location of all grid points along this edge can easily be determined, Figure 3.

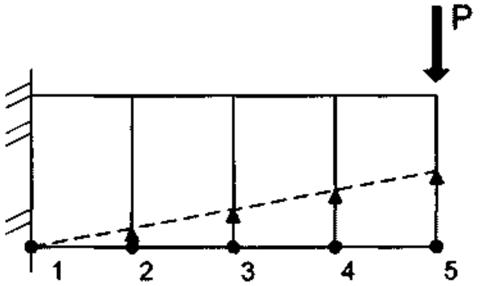


Figure 3: Variation of grid locations

If Dy represents movement of grid-5, then the grid variations can be found using the following expression,

$$\begin{Bmatrix} \Delta G_{1y} \\ \Delta G_{2y} \\ \Delta G_{3y} \\ \Delta G_{4y} \\ \Delta G_{5y} \end{Bmatrix} = \begin{Bmatrix} 0 \\ 1/4 \\ 1/2 \\ 3/4 \\ 1 \end{Bmatrix} \{\Delta y\} \tag{1}$$

Equation (1) expresses a vector of grid coordinate changes in terms of a vector of design variable changes. The column of the matrix on the right side of the equation is called a shape basis vector. Generating the shape basis vector is a primary task in shape optimization.

In geometric boundary shapes approach, the allowable shape variation is defined using only the boundary of the structure. Shape basis vectors are generated through a process of interpolation of the boundary shape changes to the interior of the structure. The shape basis vectors are updated on every design cycle, thus minimizing the problems associated with the mesh distortion for large shape changes. In this research, the approach used to generate the shape basis vectors is through running an auxiliary model.

An auxiliary model is a finite element model, which is used to generate the basis vector. An auxiliary model has geometry, element connectivity, and material type, which are the same as the real structural model. However, the boundary conditions and loading are often different, which depend to the required or expected change of shape. If this auxiliary model is analyzed, a set of displacement vectors {U} is obtained. Using these displacement components as the shape of individual grid movement, vector {U} can be regarded as basis vectors for shape optimization. As the basis vectors are obtained analytically, this approach is also called analytic boundary shapes method.

DESIGN OPTIMIZATION OF WING LOWER PANEL STRUCTURE WITH INSPECTION HOLE

This paper presents an optimization of a panel with an inspection hole of IPTN CN-235 lower wing panel. It was required to have an optimum shape of the inspection hole and the dimensions of surrounding components. The external loading used in this study was the critical loading cases of wing structure. The study concentrated on the wing lower panel with inspection hole between SIT 1460 and SIT 2900. Figure 4 shows the CN-235 and its outer wing. Figure 5 shows the SIT (stations/ sections) of the wing structure. Wing lower panel between SIT 1460 and 2900 is shown in Figure 6

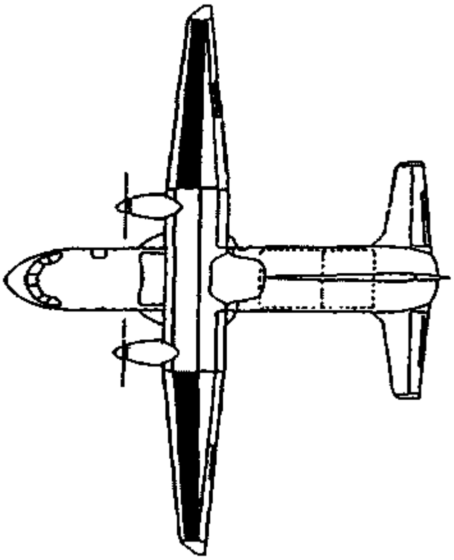


Figure 4: Outer wing of CN-235

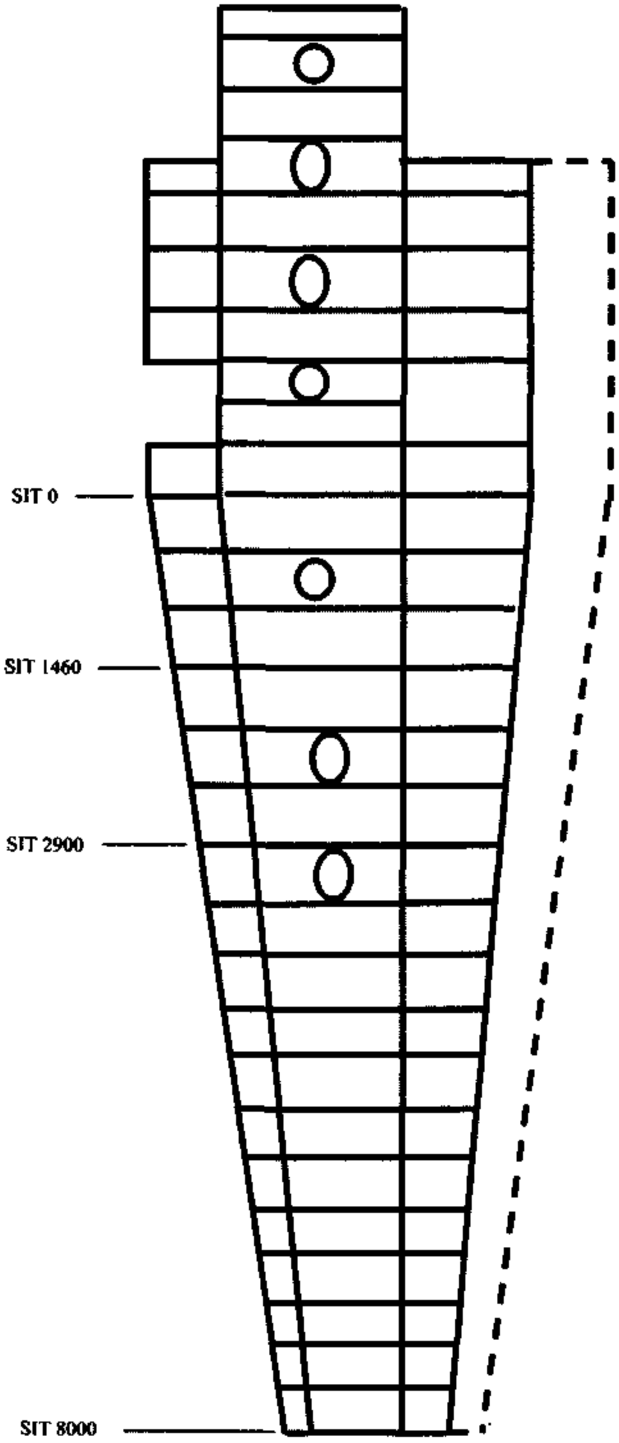


Figure 5: CN-235 outer wing SITs

Structural configuration of the lower panel to be optimized was fixed. It was in the form of stiffened panel with skin and stringers. The material used was aluminium alloy. The analysis of structure was performed by the finite element method (FEM). The types of element used were quadrilateral membrane element and triangular membrane element for skin, and rod element for stringers.

The objective was to find a least weight structure. The optimized design variables were the cross sectional area of rod elements, thickness of shell elements, and diameter of inspection hole. The design requirements were yield strength and Von Misses criteria. Static analysis was used throughout the optimization process.

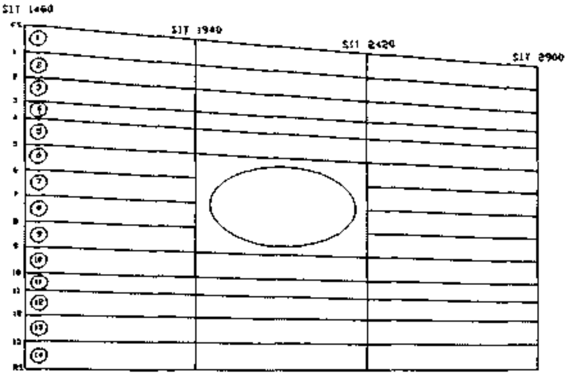


Figure 6: Wing lower panel between SIT 1460 and 2900

OPTIMIZATION PROCEDURE

The optimization was performed in the following steps:

a) The first step was running finite element analysis of the finite element model of complete CN-235 wing structure against the wing critical load cases. This was followed by identifying internal force responses in the form of loading at every nodal point (grid forces) for the required nodal points (SIT 1460 and SIT 2900).

b) The second step was applying nodal forces (SIT 1460 and 2900) of step one and optimize the design of the lower panel SIT 1460-2900 (only size optimization). Loading was applied to SIT 2900 while SIT 1460 is constrained. The loading magnitudes were the average of loading at nodes of SIT 1460 and 2900. The optimization was not performed to the inner rectangular panel surrounding the hole (bounded by coaming/main stringers and two ribs).

c) The third step was extracting (internal) nodal forces of certain nodes surrounding the holes. It should be noted that these nodal forces were forces of already size-optimized structure (step-2).

d) The last step was to perform shape optimization to the inspection hole (circular hole initially) using the obtained forces at step three.

The above procedure is illustrated in Figure 7.

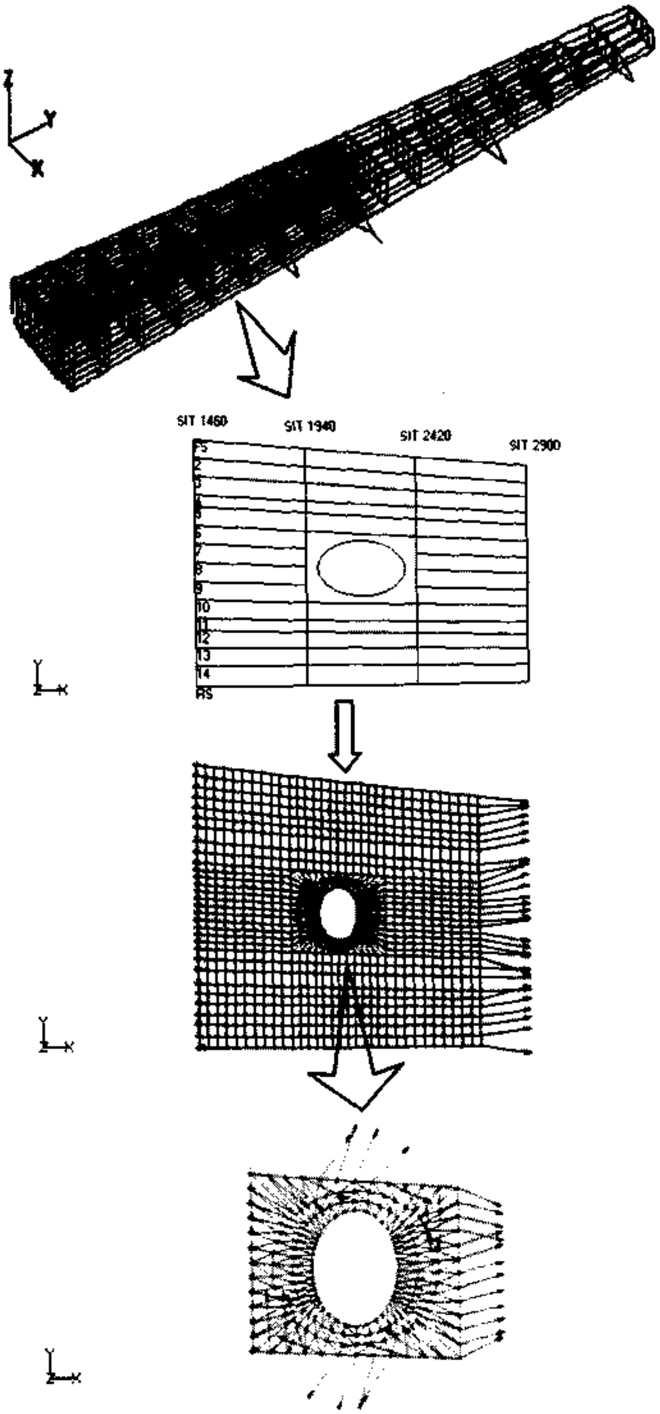


Figure 7: Optimization procedure

OPTIMIZATION RESULTS

The result for size optimization (step-2) is shown in Figure 8, 9 and 10. Figure 8 shows the weight history. Figure 9 shows the optimization history of skin thickness, while Figure 10 shows the stringers area.

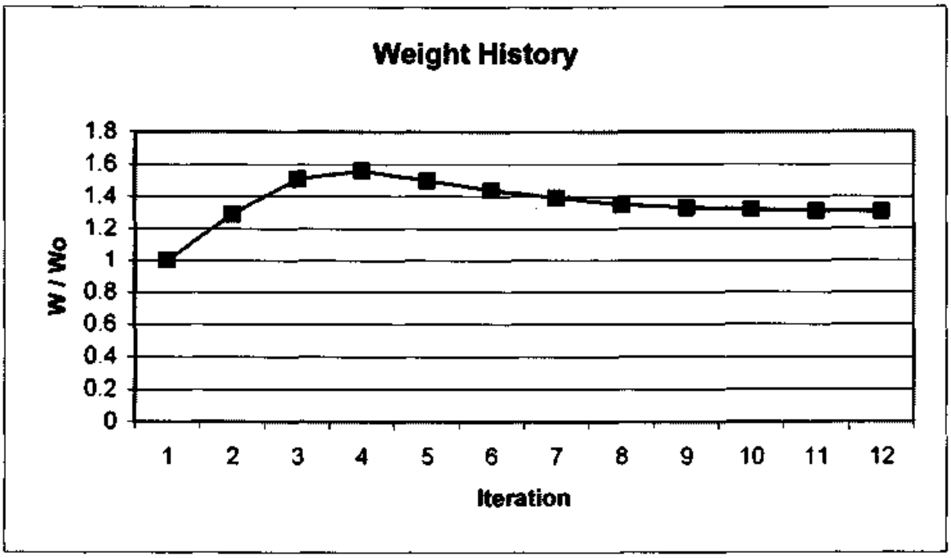
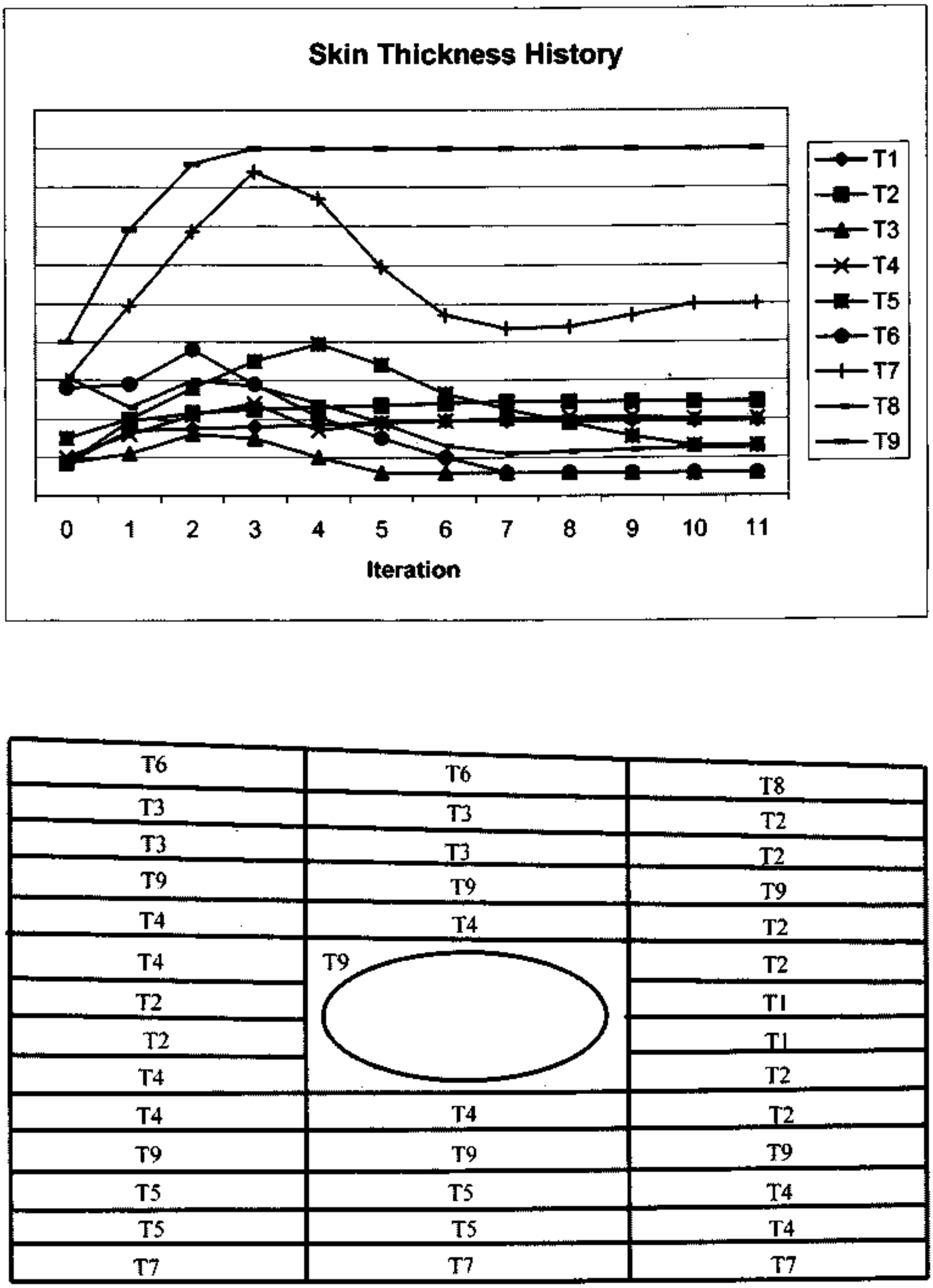


Figure 8: Weight history of size optimization

Figure-8 shows that the size optimization converging after 11 iterations. The weight is shown as the weight ratio to the initial weight. At optimum, the weight of the panel was increasing up to almost 30% of the initial weight. This means that the initial design was infeasible.



T6	T6	T8
T3	T3	T2
T3	T3	T2
T9	T9	T9
T4	T4	T2
T4	T9	T2
T2		T1
T2		T1
T4		T2
T4	T4	T2
T9	T9	T9
T5	T5	T4
T5	T5	T4
T7	T7	T7

Figure 9: History of skin optimization

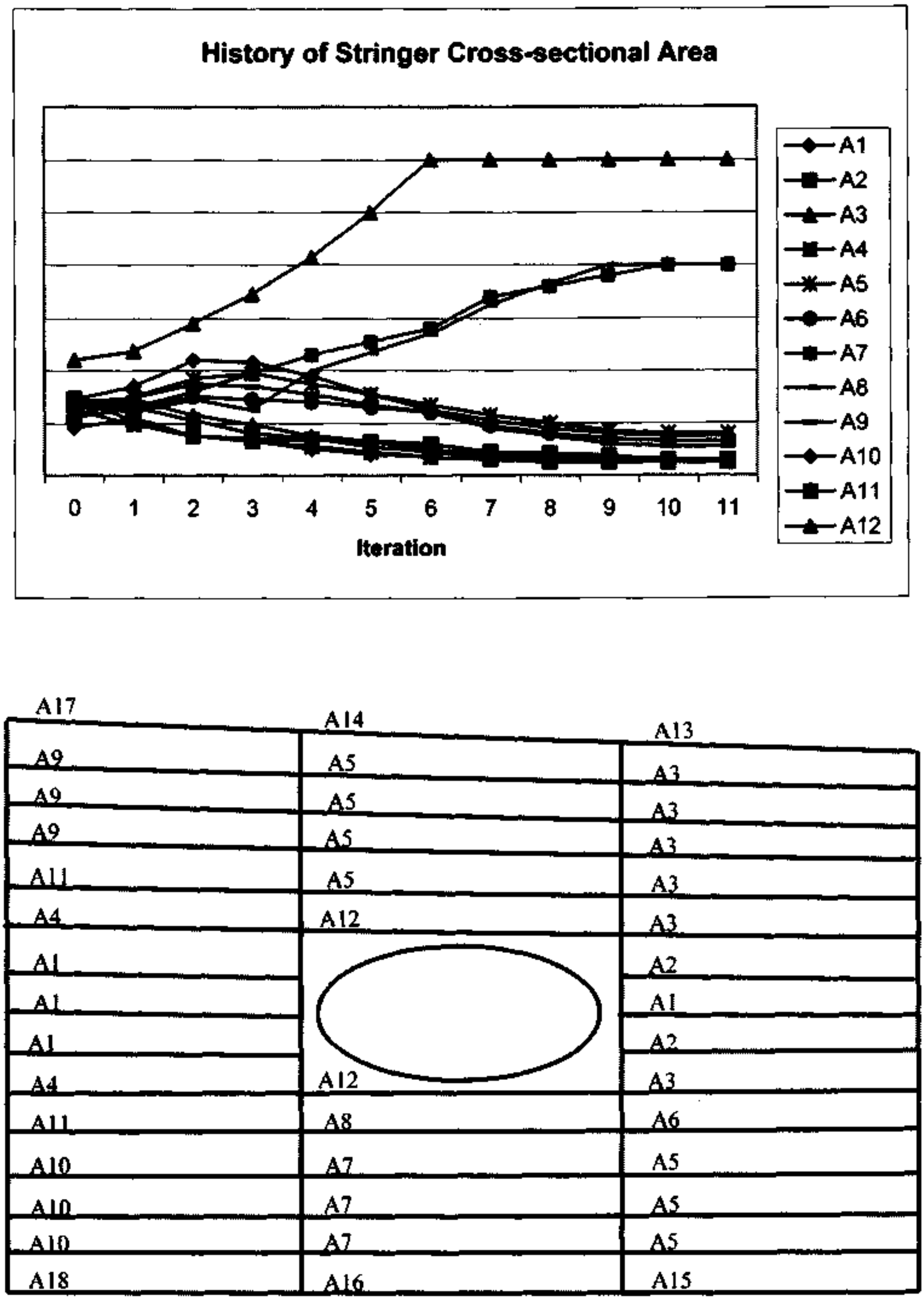


Figure 10: History of stringer optimization

Figure 11 shows the weight history of the shape optimization (step-4).

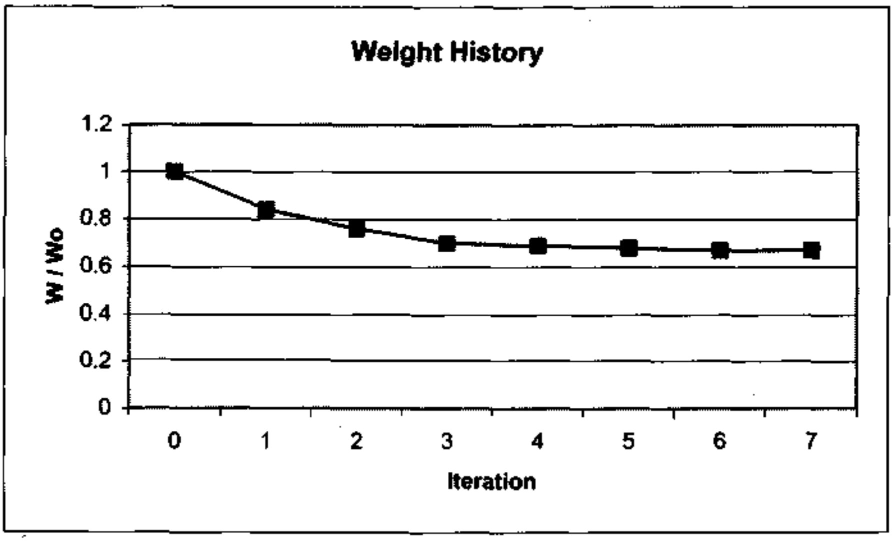


Figure 11: Weight history of shape optimization

Design variables in shape optimization is in the form of hole shape parameters. These variables are in the form of a shape variable D1 which is related to nodal movement to x-direction, and another variable D2 which is related to nodal movement to y-direction. Figure 12 shows the history of these shape design variables.

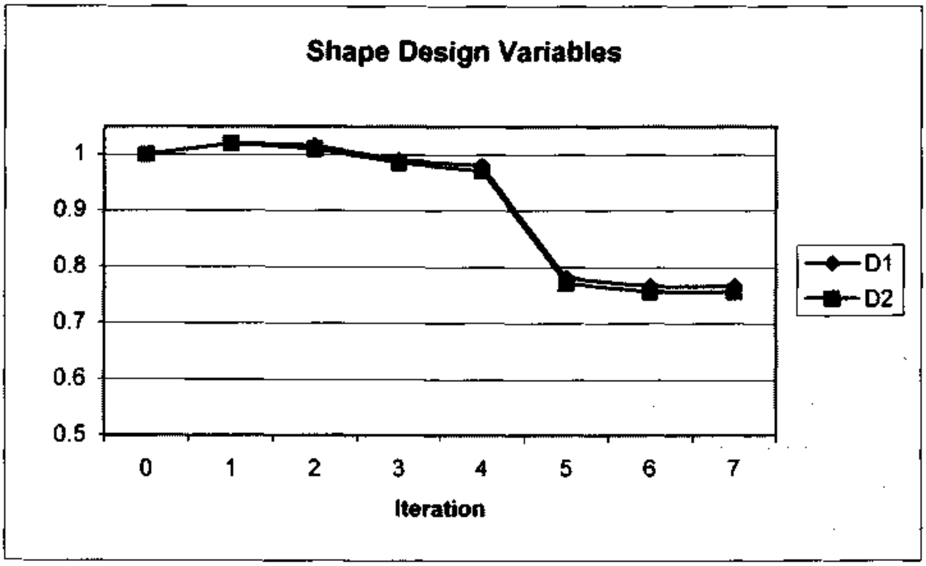


Figure 12: History of shape design variables

CONCLUSION

A research of shape optimization had been performed. The case study was the optimization of CN-235 lower wing panel surrounding the inspection hole. The loading used was the wing design loading, which was the selection of most critical design cases for every wing section.

NASTRAN could do well with regard to this optimization. It can be seen from the convergence of the optimization to a feasible design. However, the final result shown in this report has not fully validated yet as a better design compare to the existing structure. A cross-check is needed to compare the design constraint used here (yield strength and Von Misses), and the ones used for the wing original design. That was not done in this research. It also needs to mention that the actual design is also dictated by other design criteria, such as buckling and fatigue, rather than static strength criteria alone.

For this design case, the best way to do shape optimization is by performing a complete shape and size optimization at one run, instead of performing the size first and followed by shape optimization (as done in this research). The approach performed in this research was done under assumption that there was no coupling between the two optimization stages. However this partial approach was carried out as difficulties were encountered during initial trial for simultaneous optimization.

From this research, a lot had been learned with regard to shape optimization. At present, a further study is being performed to shape optimization to get a better understanding of the approach, analysis of the optimum shape design variables, and for a better application to the real problems.

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