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Multi-objective optimization design and analysis of large deformation composite material

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Multi-objective optimization design and analysis of large deformation composite material

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Abstract—In the future, advanced aircraft proposes to reduce the gaps on the surface of the body to improve the flight performance and stealth performance of the aircraft. This requires a sealing device between the movable surface of the leading and trailing edges of the wing and the fixed wing surface. Based on the sealing of the wing gap, this paper uses CATIA software combined with HyperWorks and ABAQUS software to design and optimize a large-deformation composite structure that can follow the large-scale movement of the movable surface without affecting the movement of the movable surface of the wing.

1. Introduction

There is a structural gap between the movable surface of the trailing edge of the conventional aircraft and the fixed trailing edge of the wing to prevent the movable surface from interfering during the movement. However, in order to achieve specific performance requirements, it is necessary to maintain the smooth continuity of the body surface[1]. At this time, it is necessary to set a sealing device between the movable surface of the front and rear edges of the wing and the fixed wing surface to keep the shape of the wing smooth and continuous[2].Some data show that the research and application of sealing structure has been used in foreign aircraft for a long time. For example, American B-2, F-22, F-35 and other aircraft have advanced large deformation composite material sealing. strict structure[3].

This study is carried out for this kind of sealing structure. Through material selection, shape design, multi-objective optimization of shape, arc height and layup, and finally checking, a large-deformation composite material structure that can move with the moving surface of the wing is obtained to ensure that the During the process, it always adheres to the moving surface and does not cause damage[4].

2. Preliminary structural design and modeling

2.1 Design Requirements

The shape and position of the large deformation composite structure are shown in Fig 1. In the design of this paper, it is assumed that the deflection angle of the ailerons ranges from -30° to 25° (upward deflection is +). The aerodynamic load needs to be considered in the design. The aerodynamic load distribution per unit length of the structure (spanwise 1 meter) is shown in Fig 2 below. The aileron is 30° downward, F1=-16900N/m (suction force, vertical to the object surface, pointing outward, the same below), F2=-13500N/m, F3=-13500N/m, F4=+6000N/m, F5=+ 6000N/m (pressure).

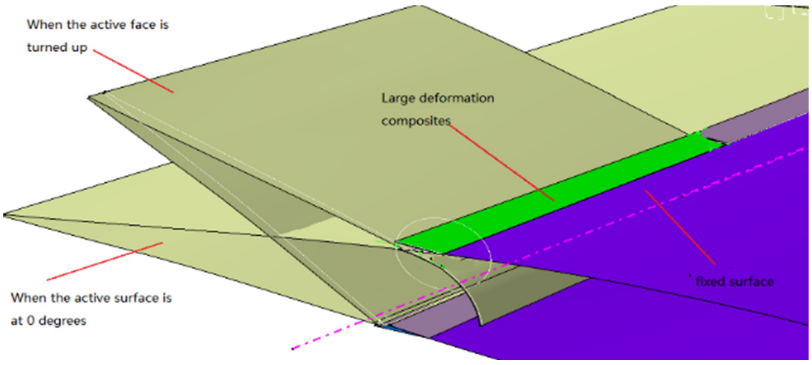


Fig.1 The shape and location of the structure

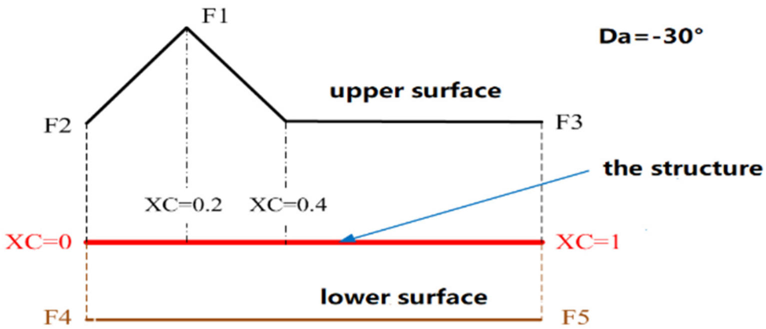


Fig.2 Pressure distribution on the surface of the structure

2.2 Select materials

Compared with metal materials, composite materials have the advantages of fatigue resistance, heat and humidity resistance, vibration reduction, etc., and its specific strength and specific stiffness are higher than most metal materials[5], and its material properties can be controlled by laying up, allowing material design and structural design to achieve a high degree of unity[6]. This design needs to meet the large deformation requirements, so composite materials are the most suitable.

The large deformation composite structure used in this study was laid with T700 and its mechanical properties are as follows: Young's modulus E1=69.4GPa, E2=63.4GPa Poisson's ratio ν=0.05, shear modulus G12=4.06GPa, G13= G23=1.05GPa, the tensile and compressive strengths in the X direction are 916MPa and 720MPa, the tensile and compressive strengths in the Y direction are 866MPa and 647MPa, and the shear strength in the XY plane is 90MPa.

2.3 Preliminary design of shape

The large deformation composite material structure with unit length along the span direction can be regarded as a kind of cantilever beam with variable section. Its parameters are mainly to determine its section shape, including chordwise width and thickness. The structure diagram is shown in Fig 3.

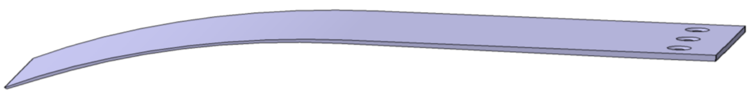


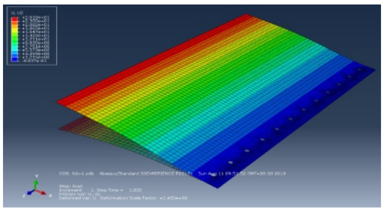
Fig.3 Schematic diagram of large deformation composite material structure

When the aircraft rotates on the active surface, the slit width also changes[7]. According to the load-bearing form and functional characteristics of the structure, the root is subjected to the greatest stress and strain, so its section should be of variable thickness[8]. Finally, the section design of the structure is: the thickness of the root is 3mm, the thickness of the trailing edge is 2mm, the maximum pre-deformation is 15mm, and the total width is 190mm.

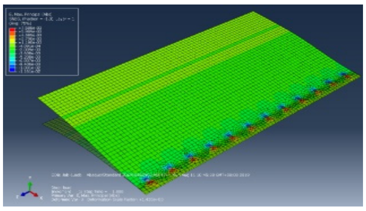
2.4 Finite element modeling and analysis

The simplification principle of the finite element model is as follows: the large deformation structure, the movable surface, and the fixed surface are simplified by shell elements, the surface of the structure is removed for meshing, and the upper surface of other surfaces is used for meshing, and the bolts use RBE3-Bar-RBE3 Formal simulation, meshing it, and the completed overall model has a total of 42321 elements. Defines the line-surface contact between the aileron and the structure.

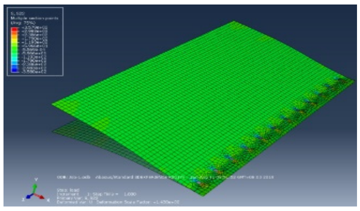
The established model is analyzed, and the results are shown in Fig 4.



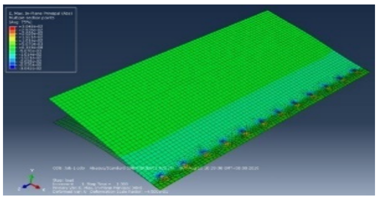
(a)Deformation under aerodynamic load



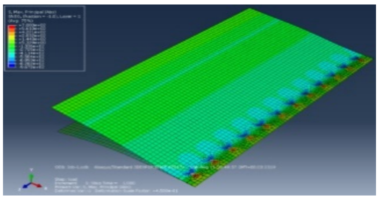
(b)Maximum strain under aerodynamic load



(c)Maximum stress under aerodynamic load



(d) Strain under large deformation



(e) Principal Stresses at large deformations

Fig.4 Analysis and calculation results cloud map

According to the calculation results, the maximum deformation under aerodynamic load is 25.5mm, the maximum tensile strain is 7568με, the maximum compressive strain is 11710με, the maximum tensile stress under aerodynamic load is 337.9Mpa, the maximum compressive stress is 378Mpa, the maximum tensile strain under large deformation is 30520με, and the maximum pressure The strain is 30520με, the maximum tensile stress under large deformation is 705Mpa, and the maximum compressive stress is 969Mpa. The analysis shows that the initial design cannot meet the design requirements of the sealing structure, and the main problems are as follows:

(1) The pre-deformation of the structure is small. Under aerodynamic load, the structural deformation will lead to the failure of the sealing function;

(2) Under the condition of aerodynamic load and large deformation, the strain of the structure is too large, and structural failure occurs. The above conclusions show that the initial design cannot meet the requirements. Optimization analysis is required.

3. Structural optimization design analysis

Based on the composite sealing structure and finite element model initially designed in the previous chapter, the preliminary optimization design of the structural shape is firstly carried out. On this basis, the arc height is optimized, and finally the lay-up is optimized.

3.1 Shape Optimization

Set 0 degree and 45 degree ply thickness and structure horizontal position, fillet radius, down bend height as shape variables. The minimum contact force of the restraint aerodynamic condition is not less than 150N, and the maximum contact force of the restraint rotation condition is not more than 4000N. The optimization objective is to minimize the maximum strain of the element.

The maximum strain cloud map of the structure after the optimization of Hyperstudy is completed is shown in Fig 5. At this time, the spanwise width of the structure is 180mm, the height of the arc segment is 18mm, and the radius of the arc segment is 500mm; the thickness distribution (fixed end to free end): 3.6mm, 3.2mm, 2.4mm, 2.4mm, 2mm.

3.2 Optimal design of arc height

Since the aileron opening is not covered by this large deformation composite material structure, the width of the adjustment structure is now 64mm longer. At this time, the spanwise width of the structure is 244mm and the arc height is 52mm.

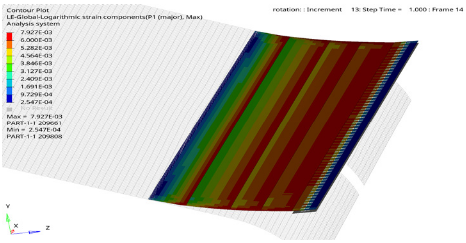


Fig.5 Structural Maximum Strain Contour

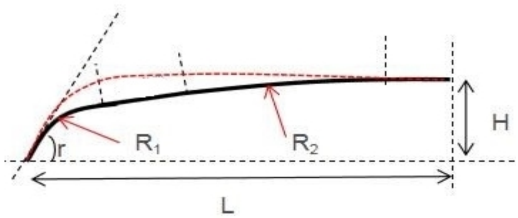
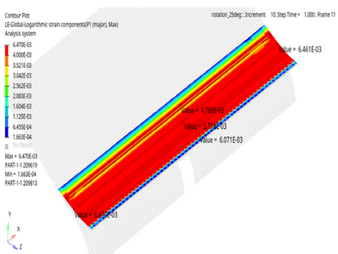


Fig.6 Schematic diagram of cross-section optimization

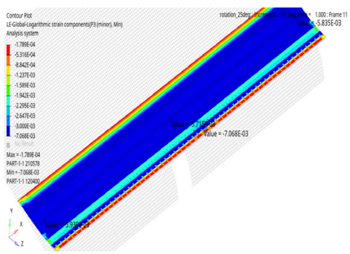
The design variable is the arc height, and the contact force between the structure and the airfoil is greater than 10N when the constraint is -20°. The optimization objective is the minimum arc height. After applying Hyperstudy and ABAQUS optimization, the spanwise width of the structure is 244mm, and the arc height H=35mm. At this time, the sealing plate and the aileron are not separated at -20 degrees under aerodynamic suction load, and the separation is 2.94 mm at -30 degrees.

After the previous optimization, the structure was separated at -30 degrees, which did not meet the design requirements. Therefore, the structural section is designed from one arc to two arcs, and the two arcs are optimized. As shown in Fig 6, R1: 150mm, R2: 800mm; arc height: 29mm; maximum tensile strain: 6497με; maximum compressive strain: 7059με; maximum shear strain: 4408με. By optimizing the design of the cross-sectional shape, the design requirements are basically met at this time, and no separation occurs.

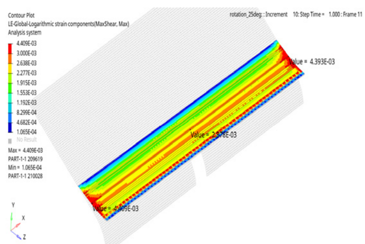
The nephograms of tensile strain, compressive strain and shear strain at 25° are shown in Fig 7:



(a)Structural Tensile Strain Contour



(b)Structural compressive strain cloud map



(c)Structural Shear Strain Contour

Fig 7 Structural Tension, Compression, Shear Strain Contours

3.3 Layer optimization of sealing structure

Before optimization, the structure needs to be thickness partitioned as shown in Fig 8; then a super layer is created for each regional layer property, and the 0 degree and 45 degree layer thicknesses are set as optimization variables. Set arc height, radian and arc length as optimization variables. The optimization objective is to minimize the maximum strain of the element.

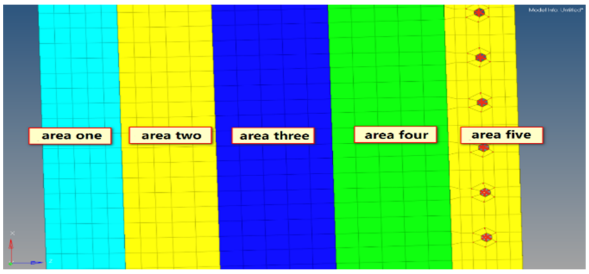


Fig 8 Schematic diagram of layer thickness division

After optimization, the layers are as follows: 2.4mm (45°, 0°, 0°, 45°, 45°, 0°); 2.8mm (45°, 0°, 45°, 0°, 45°, 45°) °, 0°); 3.2mm (45°, 0°, 45°, 0°, 45°, 0°, 45°, 0°); 3.6mm (45°, 0°, 45°, 0°, 45°) °, 0°, 0°, 45°, 0°); 4mm (45°, 0°, 45°, 0°, 0°, 45°, 0°, 0°, 45°, 0°).After optimization, the revised model is calculated, and the calculation results are summarized: the maximum tensile strain is 6240με; the maximum compressive strain is 6267με; the maximum shear strain: 4386με.

The nephograms of tensile strain, compressive strain and shear strain at 25° are shown in Fig 9:

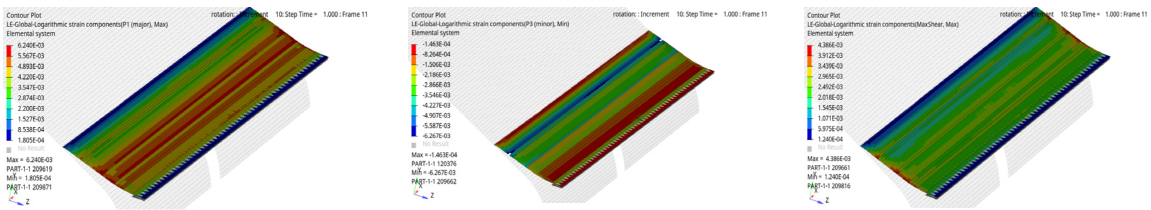

(a)Structural Tensile Strain Contour (b)Structural compressive strain cloud map (c)Structural Shear Strain Contour

Fig 9 Tensile, compressive, and shear strain contours of the structure after ply optimization

By optimizing the structure, the layering sequence of the sealing structure is confirmed. The basic parameters of the final optimization are as follows: the thickness of the layers is 4mm, 3.6mm, 3.2mm, 2.8mm, 2.4mm, and 4mm; The strain in the direction meets the design requirements.

The calculation method of structural safety margin is:

$$M.S. = \frac{\varepsilon_{bru}}{\varepsilon_t} - 1 \tag{1}$$

$[\varepsilon_{bru}]$——Ultimate Strain of Composites, $[\varepsilon_t]$——Composite Calculated Strain

The new structure of the sealing structure is checked according to the above check method, and the check results are summarized in Table 1.

Table 1 Summary table of check results

Check content	maximum calculated value	material limit	safety margin
Maximum tensile strain (με)	6240	10000	0.60
Maximum compressive strain (με)	6267	12000	0.91
Maximum Shear Strain (με)	4386	12000	1.74

The safety margins are all greater than 0, meeting the design requirements

4. Conclusion

In this paper, taking the gap of the aircraft wing as the research object, a large deformation composite structure that meets the requirements is designed and optimized. By selecting the material, designing the shape, modeling, and using the Hyperstudy optimization platform to call the ABAQUS solver to optimize its shape, arc height, and layering. Finally, the arc height of the structure is determined to be

H=29mm, the width is 244mm, and the layer thicknesses are 4mm, 3.6mm, 3.2mm, 2.8mm, 2.4'mm. The design results basically meet the design requirements and remain in the process of following the movement of the moving surface. fit without damage.

There are still many areas to be further studied in this research, such as optimization algorithm, damage evolution, fatigue and so on. It can be further analyzed and studied in the follow-up work.

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