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Integrally Panel Strength Design Method of the Thick Skin for "T"

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Abstract: Based on the design methodology of the integral panel in the "aircraft design manual", the structure with the higher load-carrying capacity can be obtained under the optimal design area ratio. However, the determination of the of the separation surface location between the skin and the stringer is great obstacle during the actual design work. In this paper, some research works have been done to solve this problem. For the T-shaped integral panel with skin thickness ranging from 4mm-6mm, the position of a separating surface has been determined, and the area ratio of the skin to the stringer has been determined. At the same time, the optimal design area ratio of the skin to the stringer is obtained by calculation and experimental verification under the condition that the structural quality is certain and the maximum unstable load is taken as the design objective. The 4mm-6mm-thickness skin T-shaped integral panel designed with this area ratio has the strongest ability to bear axial compression load and the smallest structure weight. This paper makes up some defects of the integral panel design in the data, provides some basic data support for the majority of aircraft designers, and facilitates the engineering designers to carry out fine design work and improve the quality of aircraft design.

Keyword: T-shaped Integral Panels, The Ratio of the Area, Axial Compression Load

1. Introduction

Aircraft structure design analysis and test technology is one of the key technologies of aircraft research and development, and the high pursuit of comfort, safety, reliability, maintainability and economy of civil aircraft makes the related technology of aircraft structure design develop rapidly. At present, the design factors of high structure efficiency, long life, good maintainability and high reliability are the main focus of civil aircraft design. Therefore, the study and application of integral panel structure is one of the effective ways to improve the performance of civil aircraft. Mastering and flexibly using integral panel design technology has become a key factor to access whether the aircraft structure design level is high or not.

The integral panel structure refers to the panel structure which is produced into an integral whole without riveting, gluing, welding, screw-joint and other common structure connection technologies. Comparing with riveted panel, integral panel has the following advantages [1, 2]:

With the same stiffness/strength, the structure mass can be reduced by 15% ~ 20%;

1) As the number of connecting rivets is reduced, the airtightness of the whole oil tank is improved and the use of sealing materials is reduced;
2) Due to the reduction of the account of connecting holes, the net area of the section is increased, and the fatigue life of the structure is improved;
3) The number of parts should be reduced at least 80%, the assembly workload should be reduced at least 67%, and the coordination relationship should be simpler and clearer;
4) The contour is accurate, the flight resistance is reduced and the flight performance is improved.
5) Due to the obvious advantages of integral panels, it has always been the research and application direction of airlines all over the world. The capability of applying integral panels to the wings of contemporary aircraft has reached 87%. With the leap of modern manufacturing level, the supply size of the whole panel in China has reached 19000mm×31150mm. Therefore, studying the application of the whole panel has become an important

requirements of aircraft design technology.

2. The Determination of the "T" Shape Integral Panel Separation Surface

The design of the integral panel is based on the principle of improving the inertia radius (ρ) of section. the larger of the inertia radius, the higher the critical stress of the panel. For the integral panel with "T" shaped section, it has become a common design section in aircraft design due to its simple machining process and low machining cost. However, there are very few integral panel design research results in China. Among these references, the optimal section area ratio of the stringer and the skin is about 1.4 when the compression instability stress of the stringer and the skin is equal; but the optimal ratio is about 1.7 when there is without flange on the integral panel [3], As an integral panel structure, it is difficult to determine the position of the separation plane when it is according to determining the section area of the stringer and skin. For "T" shaped integral panel, there are at least three schemes of separation surface layout between the skin and the stringer，As shown in the figure 1.

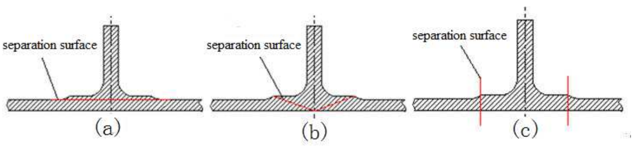


Figure 1. *Position of separation surface of "T" shaped integral panel.*

According to this difficulty in design and on the standpoint of actual engineering requirements, the design of "T-shaped" integral panel is carried out on the assumption that its separation surface is shown in Figure 2.

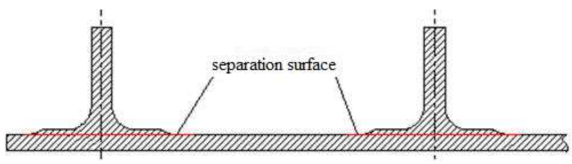


Figure 2. *Assumed separation surface position of skin and girder.*

3. "T" Shaped Integral Panel Design

On the premise of the same structural weight, the design of the "T" shaped integral panel is carried out with the determined unstable load as the design objective, and the influence of the load magnitude designed by the model, effective space of the wing box, test cost and duration and other factors are comprehensively considered. The following requirements are put forward for the design of the integral panel:

a) The buckling load is greater than 1300kN;
b) The thickness of skin is between 4mm to 6mm, and the height of stringer is 42mm;
c) The area ratio of skin to stringer is carried out by 4 types of area ratios;
d) Contour is regarded as a plate.

According to the above conditions, the size of the stringer was optimized [4], Section size labeling is shown in figure 3, and design section parameters are shown in table 1.

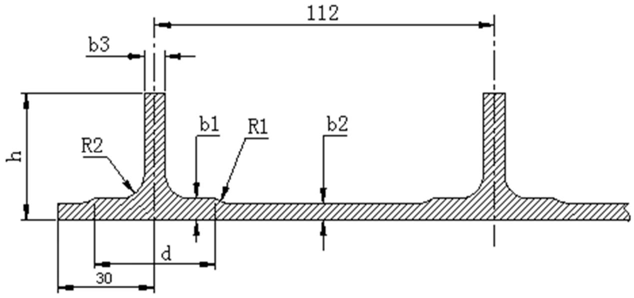


Figure 3. *Schematic diagram of integral panel section dimensions.*

Table 1. *Design parameters of overall panel section.*

number	b_1/mm	b_2/mm	b_3/mm	total cross-sectional area	area ratio
1	7	4.8	8.1	3099	1.45
2	7	5	7.8	3092	1.59
3	7.2	5.2	7.4	3097	1.73
4	7.2	5.5	7	3094	1.98

Notes h=42mm d=40mm R_1=12mm R_2=8mm.

The integral panel structure composed of 1 rib spacing and 3 stringer spacing was selected for experimental study. In order to prevent the side effect of the test specimen, the side skin is extended appropriately during the design of the test specimen; At the same time, considering the need of loading and constraint, the test specimen length was extended toward 2 directions. The design scheme of the "T" shape integral panel is shown in figure 4.

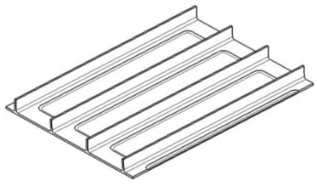


Figure 4. *"T" shaped integral panel.*

4. Finite Element Calculation Research

Through analysis, the finite element calculation model of the whole panel structure is established by using plane bending plate elements that can reflect the bending effect of the panel. The finite element model and coordinate system are shown in figure 5.

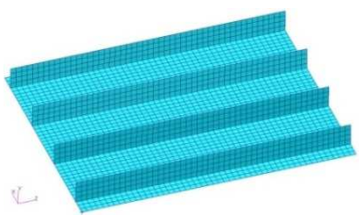


Figure 5. *Finite element model and coordinate system.*

Symmetric constraint is used in The model. After applying the corresponding load on the two ends of the finite element model, Lanczos vector method is used to conduct eigenvalue analysis on the siding through Nastran software instability analysis module (SOL105) [5-7]. The calculated buckling load according to the design section size is shown in table 2. The first-order instability modal cloud diagram is shown in figure 6 ~ figure 9.

Table 2. *Buckling load of the wall plate composed of each section.*

number	Characteristic load	Buckling load /kN	Eigenvalue cloud	Area ratio of skin to stringer
1	24610	1452.0	Figure 6	1.45
2	24064	1420.0	Figure 7	1.59
3	23376	1379.2	Figure 8	1.73
4	22607	1333.8	Figure 9	1.98

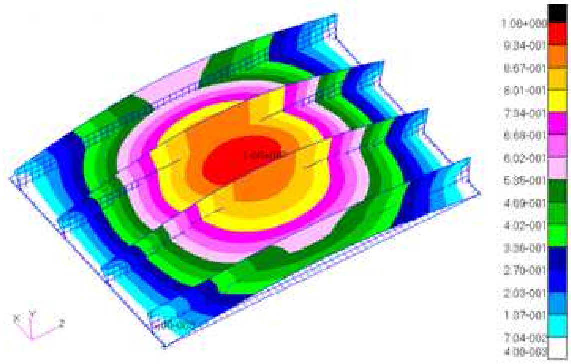


Figure 6. *Eigenvalue cloud diagram of no. 1 test piece.*

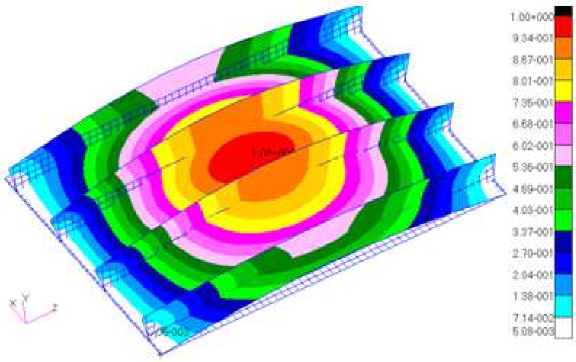


Figure 7. *Eigenvalue cloud diagram of no. 2 test piece.*

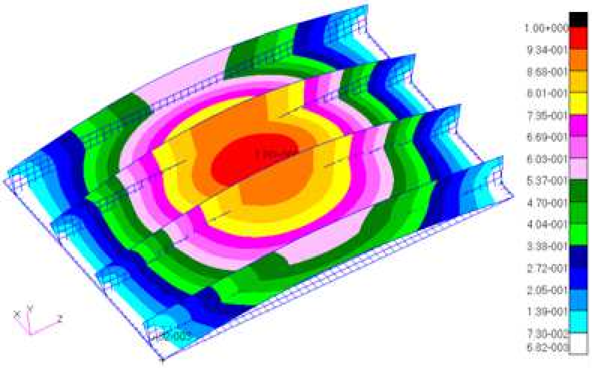


Figure 8. *Eigenvalue cloud diagram of no. 3 test piece.*

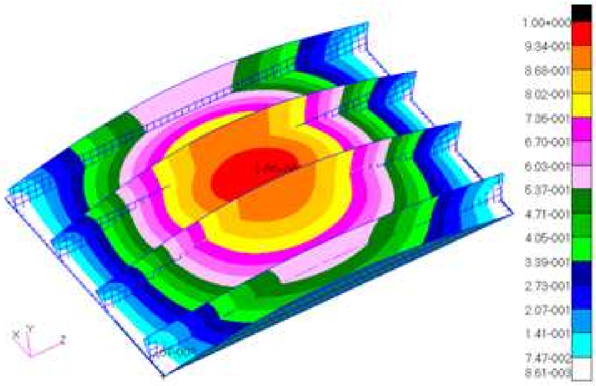


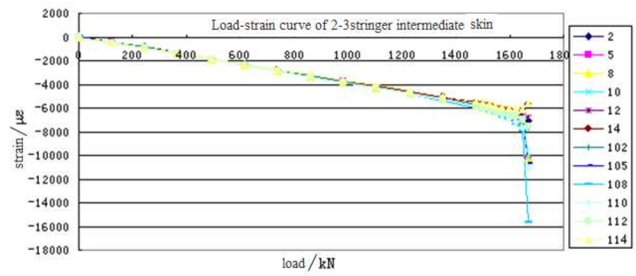
Figure 9. *Eigenvalue cloud diagram of no. 4 test piece.*

According to the analysis, the overall instability of the test specimen occurs in the process of loading until the test specimen loses its load carrying capacity. According to the calculation results, the maximum buckling load is about 1452kN. Since the calculation adopts the material linear buckling module and no nonlinear analysis is introduced, the actual load carrying capacity of the designed integral panel should be larger than the calculated value [8, 9].

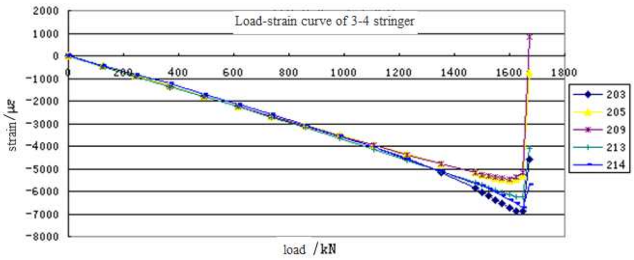
5. Verification by Axial Compression Test

According to the designed section parameters, 4 test specimen were produced for each set of parameters, and 16 test specimen were tested under axial compression. The axial compression test was carried out at room temperature [10-12]. The state before and after the failure of the test was shown in figure 10. Since the instability mode of the test specimen is almost the same, the load-strain curve of the typical position is shown in Figure 11.

Figure 10. *Before and after failure of "T" shaped integral panel during axial compression test.*



(a) skin



(b) stringer

Figure 11. *Load-strain curves at typical locations.*

Table 3. *Axial compression test results of "T" shaped integral panel.*

number	Buckling load /kN	Breaking load /kN	Area ratio of skin to stringer
1	1610	1672	1.45
2	1598	1655	1.59
3	1598	1661	1.73
4	1499	1577	1.98

6. Result Analysis

Figure 12 shows the curve of buckling and failure loads with the change of area ratio of skin to stringer. It can be seen from figure 12, the influence trend of the area ratio instability load and failure load is consistent. When the area ratio increases from 1.45 to 1.59, the instability/failure load decreases slightly; when the area ratio increases from 1.59 to 1.73, the instability/failure load basically remains unchanged; when the area ratio increases from 1.73 to 1.98, the instability/failure load decreases significantly.

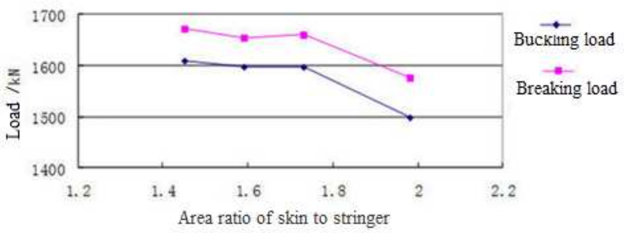


Figure 12. *Influence of area ratio on buckling load and breaking load.*

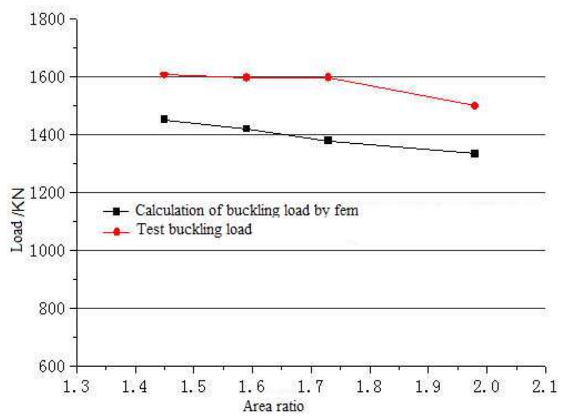


Figure 13. *Calculation and test results of buckling load.*

Figure 13 shows the comparison curve between the finite element calculation results and the experimental results. It can be seen from Figure 13, the curve trend of the finite element calculation results is consistent with that of the experimental results. The load decreases gradually with the increase of the area ratio. The result of finite element calculation is 10% ~ 14% lower than the experimental value, which is relatively conservative.

The reason of analysis error is the difference in support state and the constraint state between the experiment and the finite element calculation. In the design of test support fixture, considering the influence of simple support/fixed support state on the test results, an anti-lateral displacement limiting device was added on the side of the two ends of the test fixture to prevent instability during the test process. This kind of test support condition is very close to the fixed support, which will results in a larger test load [13-15].

In conclusion, although there is a certain error between the finite element calculation result and the test value, it can also meet the requirements of engineering design in the absence of effective test data support.

7. Conclusion

According to skin thickness arranging from 4 mm to 6 mm of the design of the "T" shape integral panel,, the author of this paper within the scope of the in the structure under the condition of the same weight to maximize the buckling load for the design optimization goal, with given skin and stringer separation surface to determine the bearing capacity of the highest skin and stringer area ratio, according to the result experimental study on the design work can be used to provide the guideline in the actual engineering practice [16, 17].

Since the design of the integral panel itself is a relatively complex problem, it is required to reduce the weight of the structure as much as possible on the premise of obtaining a higher load carrying capacity, which is a contradictory topic. However, due to the limits of time and expense, the sub-samples account used in this paper is small when obtaining the best skin to stringer area ratio, and the overall design idea of the integral panel is only given in the aspect of design method. In the future, the sampling number and scope of the area ratio between skin and stringer will be increased. At the same time, the feasibility of applying the research results to riveted/screw-welded panel structure should be studied to further expand the application scope of engineering design.

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