Some new techniques for aircraft fuselage skin tests

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1. Introduction

After the disaster of the Comet, the aircraft engineering world began to realize the vital importance of the full-scale test of an aircraft structure. These full-scale tests are the only way to ensure that any major design and production failure can be detected and eliminated in time. But, from the designer’s point of view, tests on components or even on small specimens can be of great value to evaluate a design philosophy or calculation methods. Numerous test techniques were developed during the past few decades for various aspects of an aircraft structure. According to the author’s opinion, no valid testing technique on small specimens was developed for the fuselage skin.

To investigate the fatigue behaviour of an aircraft fuselage skin, one has to consider two major aspects of the loading conditions existing in an aircraft fuselage skin:
1. the biaxial load condition, and
2. the curvature effect.

In this report, a brief review is given concerning these two aspects and some new testing techniques are introduced.
2. Biaxial fatigue testing techniques

Several authors have reviewed the existing biaxial testing techniques (ref. 1, 2, 3). These techniques include:

1. Cruciform specimens. Cross-shaped specimens are loaded in two perpendicular directions. The complete range of biaxial stress ratio, i.e., $1 >= \lambda >= -1$ can be obtained with this technique;

2. Thin-walled tubes subjected to axial tension-compression plus (a) torsion loading where the range of stress states available is limited to $0 >= \lambda >= -1$, or (b) internal-external pressure which increases the stress states available to $1 >= \lambda >= -1$;

3. Bulge-testing where round or oval-shaped plates are clamped around the periphery and subjected to fluctuating pressure on one or both sides. An equibiaxial stress state ($\lambda = +1$) can be produced in the center area of the round plates whereas the oval-shaped plates produce biaxial stress ratio of $+1 > \lambda > 0$;

4. Reversed bending of wide cantilever specimens. A biaxial stress ratio of $\lambda = 0$ can be produced by varying the width-to-thickness ratio; and

5. Anticlastic bending of square rhombic-shaped plates. The range of biaxial stress ratio is $0 >= \lambda >= -1$ depending on the ratio of the length of the major and minor axes.

All these techniques have their advantages and disadvantages. Two methods are used most frequently:

1. the cruciform specimen techniques, and
2. combined tension-torsion of thin-walled tubular specimens (fig. 1).

Both the advantages and disadvantages are summarized by Beaver in his review (ref. 1). Obviously, the combined tension-torsion of thin-walled tubular specimen is unsuitable for aircraft fuselage skin studies because of the geometry of the specimen. The cruciform specimen is excellent for static biaxial loading studies. However, in fatigue the corners of the specimen may give problems due to high stress concentrations. The thickness of the test section has to be reduced which is a problem in the case of testing sheet materials. Besides, a special testing rig is needed and the specimens may be difficult to produce.

To overcome these problems, an attempt has been made to design a new biaxial testing system which is suitable for aircraft fuselage skin tests and which does not need a special test rig. This
research has led to a completely new design called: SUPERBAT which stands for Specimen Using Poisson's ratio Effect for Bi-Axial Testing. The idea behind this technique is to create a bi-axial test area by restraining the lateral Poisson contraction in a plate-material. This idea is realized by carefully bolting steel strips onto the sheet specimen. An example is given in fig.2. The biaxial stress ratio in the center section of the specimen can be varied by varying the distances between the bolts and the number of the strips. Obviously the maximum biaxial stress ratio to be obtained is equal to the Poisson ratio υ of the sheet material. The biaxial stress field created by this method has a flat bottom form as shown in Ref.7. A very important advantage of this technique is that the specimen is suitable for existing uniaxial loading rigs. Moreover the specimen is easy to produce. This technique has also the potential to be used for a curved sheet to create a biaxial stress field.
3. Curvature effect

Only a few literature sources can be found concerning the curvature effect on the crack-growth behaviour and the residual strength of a cracked sheet. T. Swift (ref. 4) has found a larger crack growth rate in a curved panel compared to a flat panel with the same stress level (see fig. 3). Mor (ref. 5) has found excellent agreement between his test results and Follas' equation (ref. 6) for unstiffened curved panels.

It is the author's opinion (based on a private communication with Ir. Riks) that the so-called "bulge-out" effect is not only caused by the internal pressure, but is also a result of the local curvature around the crack. To investigate this phenomenon, a so-called "Curvature Effect Testing System" has been designed (fig. 4). By simply loading the specimen in tension, a very clear bulge-out effect has been observed in the cracked area. A test program has been made for further study of the phenomenon.
4. Conclusion

A brief review has been made on existing biaxial testing techniques. Two new testing systems are proposed for biaxial testing and testing of curved panels respectively. Further studies will be made using these two techniques.

5. Literatures

1. Beaver, P.W. "Multiaxial fatigue and fracture - A literature review", structures report 410, Department of Defence, Defence science and technology organization, Aeronautical research laboratories, Melbourne, Victoria, Australia, July, 1984


5. Mor, H. Crack propagation analysis of longitudinal skin crack in a pressurized cabin, 26th Israel Annual conf. on Aviation and Astronautics, Tel Aviv, Feb. 8-9, 1984


Fig. 1 EXAMPLES OF BIAXIAL FATIGUE SPECIMENS (REF. 1)

a) A CRUCIFORM SHAPED SPECIMEN

b) A THIN-WALLED TUBULAR SPECIMEN
Fig. 2 Example of SUPERBAT specimen
Fig. 3 N-2a curves for curved and flat panels (ref. 4)
Fig. 4 Example of "Curvature Effect Testing System"