NUMERICAL MODELLING OF A SELECTED PART OF THE AIRPLANE FUSELAGE

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Abstract

Analysis of a riveted lap joint, the part of M-28 Skytruck fuselage, is presented. The aim of the paper is a proper choice of finite element mesh parameters (shape and density) around the rivet hole as well as a study of the influence of different sheets thickness on secondary bending. Riveting still remains the most popular method of joining metal and composite parts of the aircraft structure. During the operation (service) the severe stress concentrations and the effects such as fretting and secondary bending occur, thus reducing fatigue life. The specimen consists of two thin sheets (0.6 and 1.2 mm thick) stiffened with a 3 mm thick frame. The parts are connected by 14 rivets (3.5 mm diameter) and 8 rivets (3 mm diameter). Overall specimen dimensions are following: length 682 mm, width 136 mm, rivets pitch 17 mm. The riveted joint is subjected to a tensile load. The analysis of large parts of structures like fuselages, wings or multi-row riveted specimens can be performed using global shell models. The correct stress state in global modelling can be obtained by taking into consideration the hole in the sheet, the rivet axis (as a rigid or beam element) and contact elements between the rivet and the hole as well as between the sheets. Deformation of the joint and stress state are calculated. Large difference between sheets thickness causes non-physical deformation of the rivet cross sections. Proper deformations of the joint are obtained by increasing stiffness of those sections in a thinner sheet. Results are compared with an experimental investigation and applied to estimations of specimen fatigue life.

Keywords: *Riveted joint, FEM model parameters*

1. Introduction

Analysis of a lap riveted specimen (a selected part of M28 Skytruck fuselage) is presented in the paper. The proper selection of the model and mesh parameters in the neighbourhood of the rivet and the influence of different sheets thickness on secondary bending of the joint are studied.

Riveted joints are permanent ones (cannot be dissembled without damaging the components). The riveting process includes a few operations: overlapping the joining components, drilling the holes, putting the rivets inside and closing them. The methods of closing (driving) solid shank rivets can be classified in two types: static and dynamic.

Riveted joints have many industrial applications. They are still widely used in aircraft structures where light weight and high strength are important. Aircraft structures, such as airplane or helicopter fuselages, wings etc. are thin–walled ones, with coverings made of thin sheets stiffened with stringers, frames or ribs. Sheets are typically assembled by multiple riveted or bolted joints. Rivets and bolts are also used to joint sheets and stiffeners. Tens and even hundreds thousand rivets may be used in a typical aircraft structure, and they have a significant influence on its fatigue performance [1].

The aim of the paper is an assessment of the load carrying capacity of a lap riveted joint which is a part of the aircraft structure. The proper mesh parameters such as its shape and density, influence of irregular rivet arrangement and various sheets thickness on stress states and secondary bending of the joint are analysed.

A selected part of M28 Skytruck fuselage is the object of analysis. This light cargo-passenger airplane is a twin-engine, high-wing, cantilever semimonocoque of an all-metal structure with maximum take-off and landing weight 7500 kg. The neighbourhood of frame No. 13, which is located in the central part of the fuselage between stringers No. 11 and 12 (Fig. 1) is analysed. This area is chosen by ILOT and PZL Mielec due to the highest stress values (amplitudes) caused during the service life.

Two thin sheets (0.6 mm and 1.2 mm thick) are jointed together and stiffened with a 3 mm thick frame. The selected fuselage area consists of 14 rivets (3.5 mm diameter) and 8 rivets (3 mm diameter) (Fig. 2).

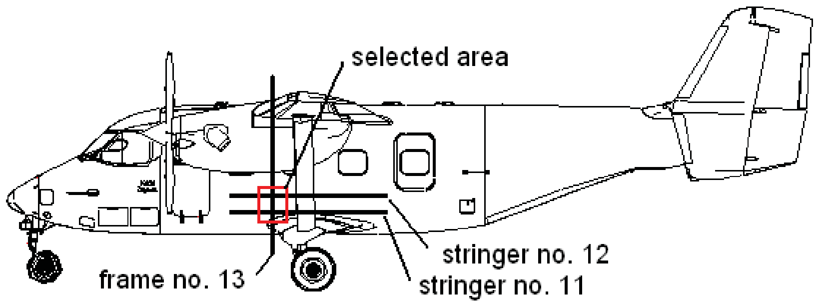

Fig. 1. Location of frame no. 13 in PZL M28 Skytruck fuselage

The riveted specimen (Fig. 3) was designed by PZL Mielec. The static and fatigue tests were performed by Institute of Aviation in Warsaw (ILOT).

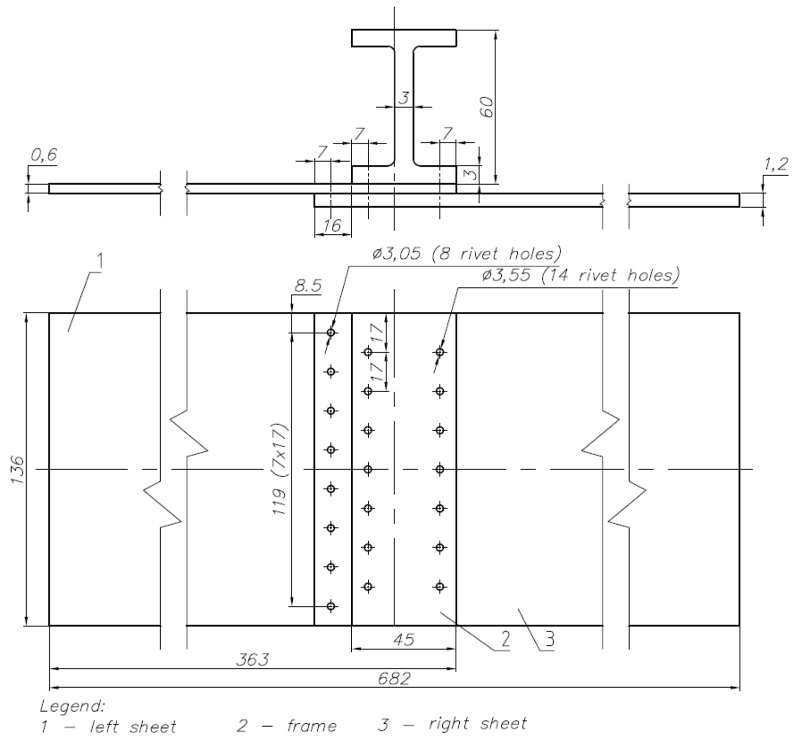

Fig. 2. Specimen overall dimensions

Fig. 3. Riveted specimen (ILOT)

2. Model of the riveted specimen

The shell model is used due to specimen geometry and the way of its loading. It allows us to define a middle surface of each sheet and shows their deformations. Both sheets and rivets cross sections models consist of four-node, isoparametric shell elements (type 139) with bilinear interpolation. Regular FE mesh and increased density around the rivet hole (Fig. 4b) are considered to obtain the correct stress state in the rivets neighbourhood.

The finite element model is made using MSC.Patran code and includes over 110 000 shell elements (Fig. 4).

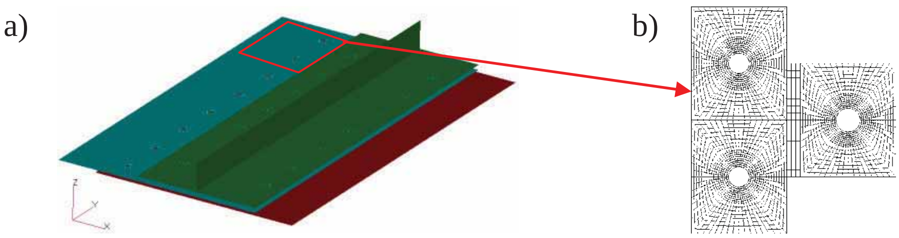

Fig. 4. FE model of the selected area

The way of rivets and rivet-sheet interaction modelling is as follows [2]:

- rivet axis is defined using a beam element with 6 degrees of freedom (Fig. 5),
- rivet shank is described as an axis and two cross sections (Fig. 5, 6),
- contact between a rivet cross section and a rivet hole is modelled with the use of contact GAP elements (Fig. 5, 6),
- rivet heads are defined with rigid RBE2 elements (Fig. 7).

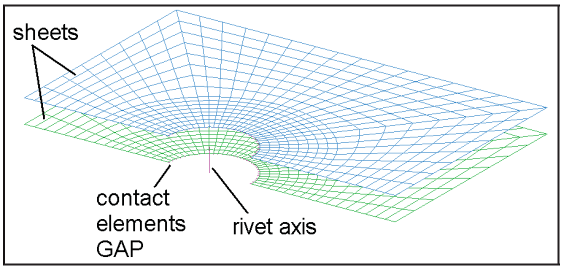

Fig. 5. Contact elements and rivet axis

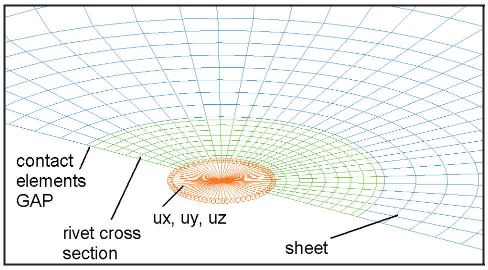

Fig. 6. Rivet cross section defined as shell elements

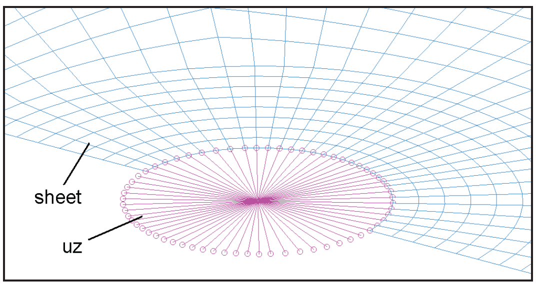

Fig. 7. Rivet heads described as rigid elements

The contact parameters between the sheets are defined with the use of Coulomb model with trial friction coefficient 0.2. The actual contact surfaces are the outer (mating) sheets surfaces, relative displacements of which are considerably larger than in the case of the middle ones, so numerical calculation of the load transferring by friction demands i.e. solid model [2, 3].

Materials used in riveted joints are subjected to high-strain deformation (plastic deformation). Multilinear material true stress – strain curve for aluminium alloy 2024T3 is presented in Fig. 8.

The magnitude of the yield stress and tensile strength are obtained from a uniaxial test so the yield value for the multiaxial state is calculated using the von Mises criterion. The elastic material model for rivets is used in analysis.

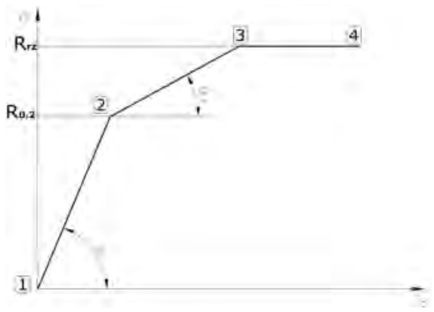

Fig. 8. Elasto-plastic material model

Boundary conditions correspond to the way of specimen fixing in the grips of the testing machine (Fig. 9). The left edge is fixed whereas the right and the frame ones have the possibility to move along x axis. Kinematic load (equal to 1 mm) is applied. The rotation possibility is blocked on the z rivets axes.

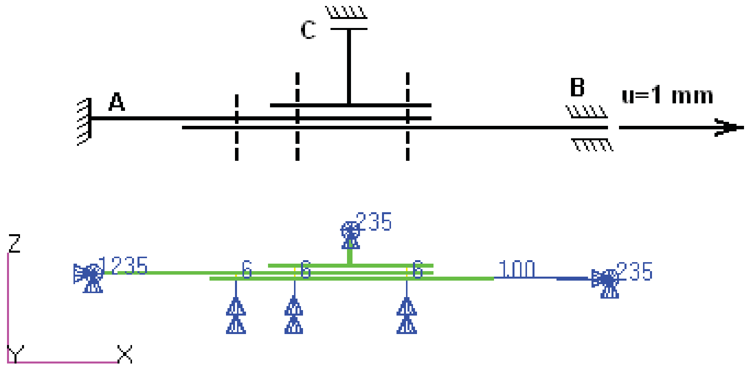

Fig. 9. Boundary conditions

2.1. Selection of finite element mesh parameters

Rivet holes in the sheets are the notches in which surroundings stress concentrations occur during loading. The finite mesh shape and density have a significant influence on numerical results. Three models with a different mesh type and four mesh densities around the rivet hole are considered (Fig. 10). The aim of analysis is to select the mesh density above which there are no significant changes of stress states and stress concentration values.

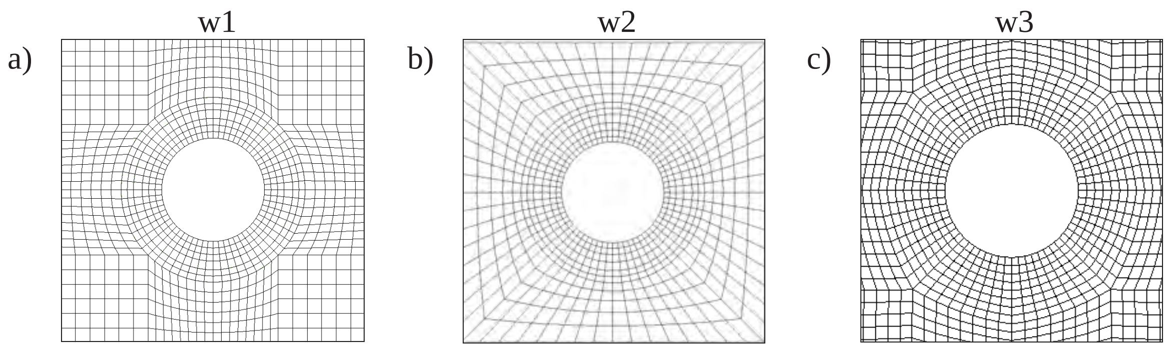

Fig. 10. Types/kinds of mesh around the rivet hole

The rivet arrangement is irregular in the target specimen. Due to this fact, two other meshes around the rivets holes (Fig. 11) are analysed in order to examine the influence of mesh distortion on numerical results. There are no significant differences observed.

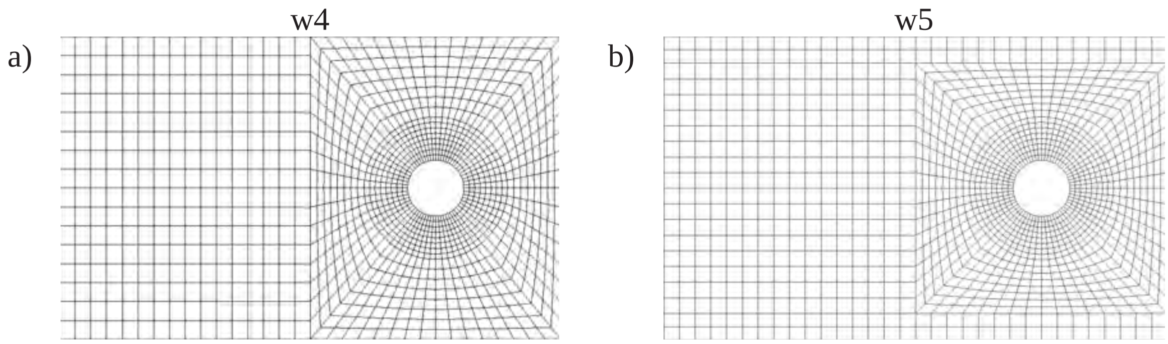

Fig. 11. Cases w4 and w5 - mesh around the hole

On the basis of numerical results the mesh type w2 shown in Fig. 10b, with 64 elements around the hole is chosen in further analyses.

2.2. Simple model of riveted lap joint

The sheets are subjected to secondary bending in the tensile loaded lap joint. It is a result of the eccentric load path (Fig. 12) [4].

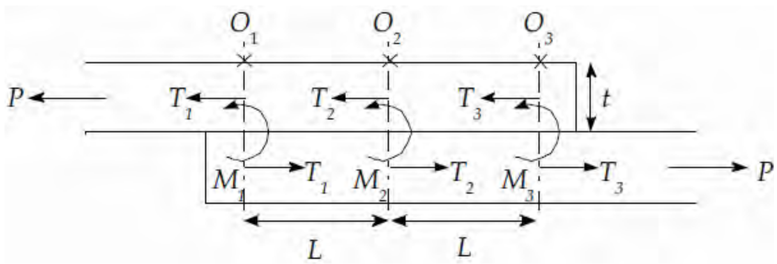

Fig. 12. Secondary bending in lap joint [4]

The differences in sheets thickness (0.6 mm and 1.2 mm) and consequently differences in their stiffness cause some difficulties during calculations. In order to select the best model parameters a simple riveted lap joint is analysed at the beginning. It consists of two sheets and three rivets (Fig. 13). This model is a part of the target one. The mesh type and density are taken according to the previous assumption.

Nonphysical deformations of the rivet cross section and consequently the whole model are recognised (Fig. 14) when sheets with two different thicknesses (0.6 mm and 1.2 mm) are used (assembled) in the joint (model e1), while the correct deformations for the sheets of the same thickness (1.2 mm) are obtained in model f1 (Fig. 15).

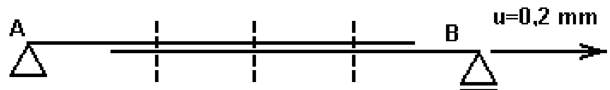

Fig. 13. Simple rivet joint

In order to improve model e1, the thickness of rivets cross sections in the 0.6 mm thick sheet is increased by changing the Young modulus. The deformations are satisfying for four time’s increased rivets cross sections stiffness (model e4) (Fig. 16).

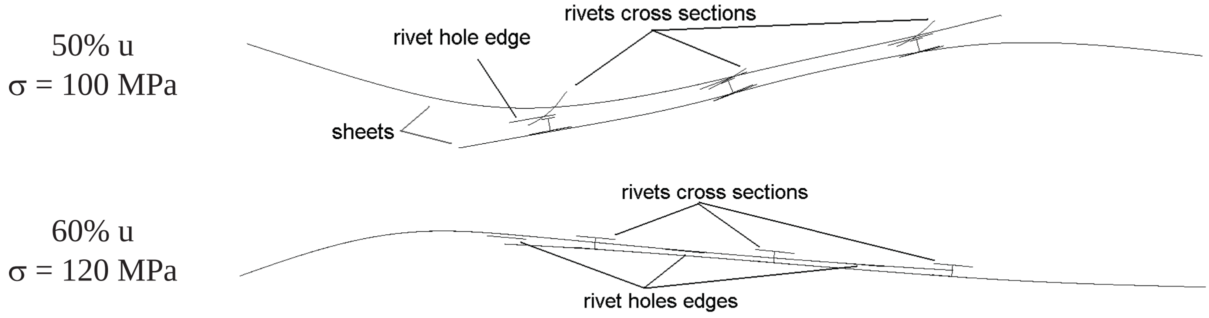

Fig. 14. Joint deformations (model e1)

Fig. 15. Joint deformation (model f1)

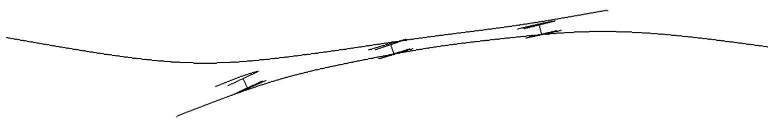

Fig. 16. Joint deformation (model e4)

3. Analysis of a structural specimen

Results from previous analyses are used to create the target model (Fig. 3). The deformations and stresses states in a tensile loaded specimen seem to be correct (Fig. 17, 18).

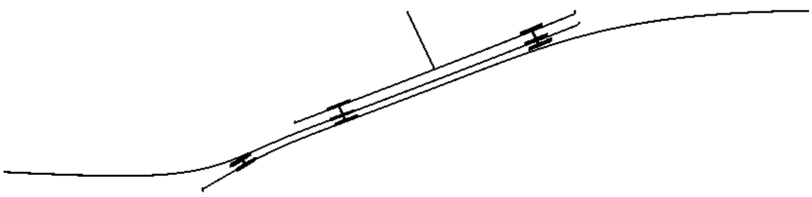

Fig. 17. Specimen deformation

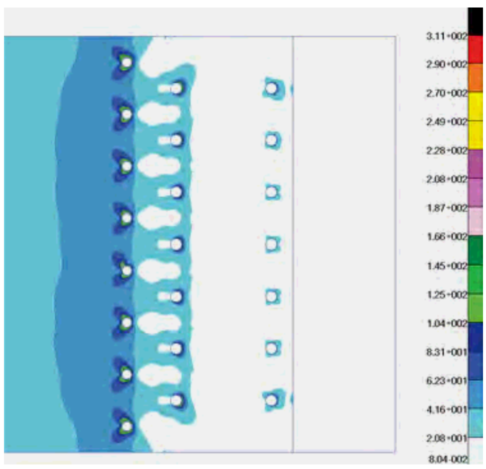

Fig. 18. Stress state in a thinner sheet [MPa]

The fatigue performance is analysed with the use of MSC.Fatigue. The fatigue life is calculated and amounted to 17 400 cycles and it is in good agreement with experimental results.

4. Conclusions

The process of correct finite elements mesh parameters selection is presented in this paper. During rivet joint analyses the problems with an irregular rivet arrangement and different sheets thickness occur.

The influence of a mesh shape and density around the rivet hole on the stress state is analysed. The better results are obtained for case w2 and this mesh type is chosen in further analyses.

The mesh distortion around the holes is necessary due to the irregular rivet arrangement and different rivet pitches, whereas it has no influence on the results of calculations.

The different sheets thickness causes nonphysical rivets cross sections deformations in the joint subjected to tensile load. The Young modulus increase causes their stiffness increasing and improves the joint deformations.

The experience obtained from analyses of simple riveted joints models allows us to create a model of a structural specimen corresponding to the part of PZL M29 Skytruck fuselage. The stress state is calculated for the selected load case and the fatigue life of the joint is successfully estimated.

Acknowledgements

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