Parametric studies on the cutouts in lightly loaded aircraft beam

SUPRIYA N M
Department of Civil Engineering, GSKSJTI
Bangalore, Karnataka State, India
priyagopi23@gmail.com

SUBRAMANYA K G
Department of Civil Engineering, GSKSJTI
Bangalore, Karnataka, India
mail2subbu.kg@gmail.com

SUBRAMANYA SASTRY SS
AGM (Tech), Engineering Vertical, Infotech Enterprises Limited
Hyderabad, Karnataka, India
Subramanya.Sastry@Infotech-Enterprises.com
http://Infotech-Enterprises.com

Abstract:
Cutouts or openings provided in the parts of the aircraft are grouped into two distinct groups. The first group is called the lightening cutouts, provided to reduce the weight of the components without compromising on the functionality and structural integrity of the component. The second group is called the functional cutouts, provided to serve the intended purpose of carrying the Environmental Control Systems, electrical wires etc., This class of cutouts not only maintains the functionality but also reinforce the affected area adequately for proper load transfer. In this paper, a systematic study of the various the factors affecting the margin of safety of a typical beam with cutouts are presented. It is to be noted that the beams are assumed to be sufficiently stiff and stable so that the strength, stiffness and stability are accounted in the design. This paper concentrates the studies on the lightly loaded beams. Two Aluminum alloys 7075-T6 and 2024-T4 are selected for the studies.

Keywords: Lightly loaded beams, Cutout, Margin of Safety, Lightening holes

I. INTRODUCTION

The aircraft structure needs to be designed accommodating many cutouts of variable sizes. These cutouts are required to provide access to control rods / cables, hydraulic lines, electrical lines etc.

The beams are classified into three classes namely, lightly loaded, medium load and heavily loaded beams. The definitions are as follows.

Lightly loaded beams

These beams are able to carry loads in their virgin form like I, ELL, TEE beams with 45^0 flange or dough nut doubler stiffeners around the cutouts. These cutouts are small to medium in size and their stress concentration effect is localized. The stresses in the immediate vicinity of the cutouts will be appreciably changed. Stresses in the far off region (beyond 2.5D, D is the diameter of the cutout) are less affected. This class of cutouts is reinforced with a doughnut doubler, forming a lip around the cutout [1]. Lightly loaded beams are also called very shallow beams. They mainly carry loads by the tension field created by the applied load. They are classified into two types as shown in Fig. 1 and Fig. 2 [2, 3].

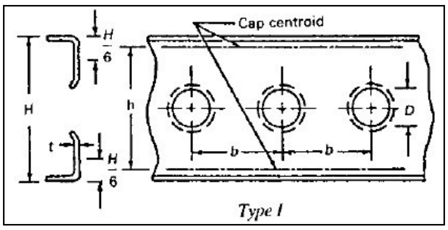

Fig.1: Cutout in the lightly loaded beams – Type 1

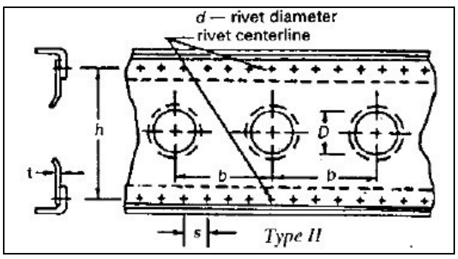

Fig.2: Cutout in the lightly loaded beams – Type 2

Moderately Loaded beams

This is the second class of beams where the beam carrying shear characterized by a flanged hole with web stiffeners between the flanged holes. In this paper a detailed study of moderately loaded beam is resented (Fig. 3). The other two classes of beams are described for the sake of completeness only.

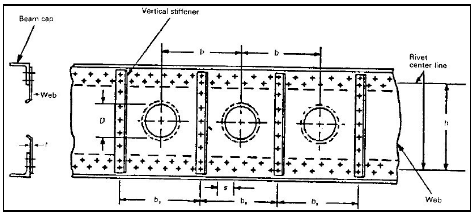

Fig.3: Cutout in moderately loaded beams

Heavily Loaded beams

The large holes in the beams are generally not recommended, but if unavoidable they must be carefully reinforced. To properly reinforce holes in heavily loaded beams, the beam has to be framed. The increase in weight due to framing can be as high as 50% as the same beam without holes. Framing means providing flanged holes reinforced by vertical and horizontal stiffeners (Fig. 4, [2]).

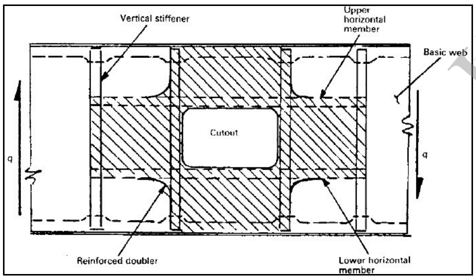

Fig.4: Cutout in heavily loaded beams

The description of the problem and various parameters used in the mathematical modeling of the medium loaded beams are presented in the next section.

II. ANALYTICAL MODELING

The beam considered for the study at present is described below.

Type of the beam: Simply supported beam

Length of the beam: 39.37 inch (1 m)

Shear flow in the web: 300 lb/in (52538.05 N/m)

Height of the web: 3 in (0.0762 m)

A list of parameters used in this study is provided below.

M.S – Margin of Safety

n = (L/b) – Number of holes

A0 = L*h – Total area of web

A_r = n*3.14*D2 - Area of material removed

q – Shear flow (lb/in)

A_g – Gross area of web

W_r – Weight reduction

L – Length of beam

b – Spacing between cutouts

h – Depth of beam

$q_{\_all}$ – Allowable shear stress

t – Thickness of web

F_s – Allowable shear stress (ksi)

f_s – Computed shear stress (ksi)

A typical drawing of the cutouts under study is shown in Fig. 5.

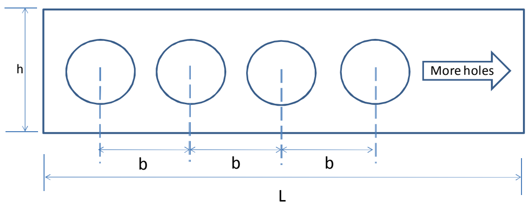

Fig.5: Pictorial view of a problem under study

III. LOADS AND BOUNDARY CONDITIONS

The beam under study is assumed to be a simply supported beam. This beam represents typical beams like

- Flap beams
- Control surface beams

The loading on the beam is assumed in the form of a shear flow (numerical value is given under Section 2). This shear flow is a typical characteristic of a class of beams called shear beams. Shear beams are short beams which fail primarily by shear than bending.

IV. MATERIALS

The beam under study is assumed to be made of two different materials.

1. Aluminium alloy 7075–T6
2. Aluminium alloy 2024–T4

V. ANALYSIS

The steps of the analysis are summarized below.

1. The shear flow (q) and height (h) of the web are noted.
2. Determine the optimum cutout diameter and spacing. Calculate $f_s = (q/t)$ and (h/t).
3. Determine the F_o from Fig. 6. And hence K_1 from the relation $F_s = K_1 * F_o$.
4. Calculate $q_{\_all}$ as $K_1 * F_o * t$.
5. Calculate the margin of safety by using the relation M.S= $(q_{\_all}/f_s)$-1. The lightest design is obtained when the value of F_s and f_s are almost equal.

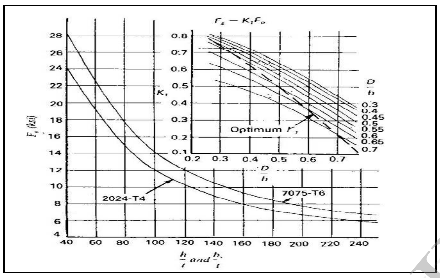

Fig.6: Allowable web stress without holes

The analysis is carried out for the following limiting conditions.

1. 0.25< (D/h) <0.75
2. 0.3 < (D/b) < 0.7
3. 40 < (h/t) < 250

VI. RESULTS AND DISCUSSIONS

The results are presented in the form of graphs and tables. Table 1 and 2 show the margin of safety obtained for the two Aluminium alloys under study. Figure 7 shows the variation of margin of safety with the spacing between the cutouts. Figure 8 shows the effect of correction factor K, on the margin safety. Figures 9 shows the variation of allowable shear flow with the ratio of diameter to spacing of cutouts.

Table 1: Computation of margin of safety (2024-T4)

[redacted]

Table 2: Computation of margin of safety (7075-T6)

[redacted]

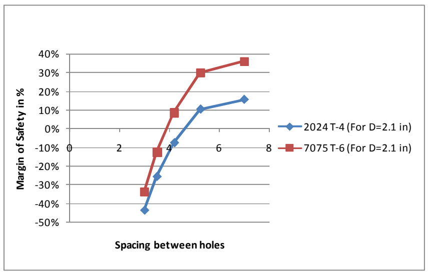

Fig. 7: Comparison of margin of safety between 2024-T4 and 7075-T6

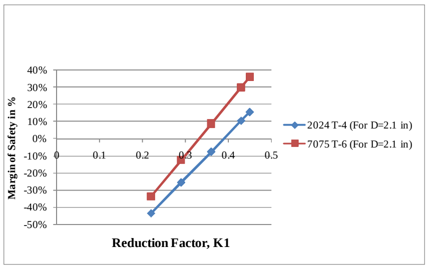

Fig. 8: Variation of MS with correction factor K_1 between 2024-T4 and 7075-T6

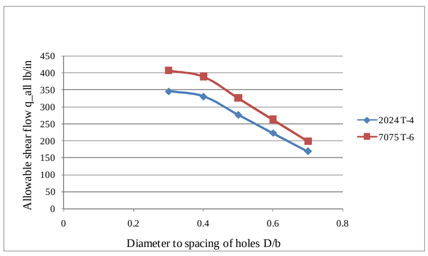

Fig. 9: Comparison of ultimate allowable web shear flow without holes between 2024-T4 and 7075-T6

The detailed study of results presented in Table 1 are presented below

1. The study is presented for a constant diameter of the cutout of 2.1in (53.34 mm).

2. From Table 1 and 2, it is observed that as (D/b) increases (means b decreases) correction factor K_1, decreases. Hence, F_o (allowable web stress without hole) decreases. As a result, the product of K_1 and F_0 also reduces. This means that as the cutout size increases, the corrected ultimate allowable stress decreases.
3. The induced stress in the web remains constant. Hence margin of safety decreases because corrected ultimate allowable stress decreases.

   4. It is observed that in general for short shear web applications, such as that under study, 7075-T6 gives higher margin safety as compared to 2024-T4. Negative margins of safety indicate inadmissible design.

VII. CONCLUSIONS

1. In lightly loaded (short shear) beams for aircraft applications, it is recommended to use 7075-T4 for lightly loaded beams.
2. Proposed procedure in literature gives acceptable results which show significant reduction in weight of the structure. Hence this procedure is adopted in the design of short beams in aircraft parts.

ACKNOWLEDGMENT

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