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NUMERICAL STUDIES ON EFFECT OF SOME DESIGN VARIABLES IN THE DESIGN OF LARGE CUTOUTS IN AIRCRAFT

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***Abstract*:** In this paper study of variables affecting the design problem of a typical rectangular cutout in a fuselage skin. This cutout is provided in a region bounded by fuselage skin stringers and frames. This study addresses the effect of various parameters influencing the design of rectangular cutout. The fuselage skin where the cutout is provided is primarily subjected to axial loading (other loadings like shear and bending is considered to be secondary in nature). Three stringer method is adopted for the detailed design of the cutout. Effect of various parameters on shear flow is studied on the sizing process.

Keywords—Cutouts, Coaming stringer Discontinuous stringer, Continuous stringer

I. INTRODUCTION

Various parts of the aircraft structure such as wing spar, fuselage frames etc., are provided with cutouts for functional and weight reduction purposes. The cutouts are essential in airframe for lightening the structure, means of providing passage for wire bundles, fuel lines, hydraulic lines, control rods, to prevent sloshing of fuel in the fuel tanks and means of providing inspection for maintenance [1 and 2]. But these cutouts are generally unwelcome from designers because the weight saved by providing the cutouts is offset by the additional reinforcement required to strengthen the region of cutout. This additional material provided also increases the cost of fabrication. This design of cutout is also difficult because it creates a region of stress concentration. This area of cutout poses a problem both of static stress and fatigue because of lack of design data to address the technical challenges associated with cutout. In this paper, the simplified procedure of cutout analysis described in [3] is examined further to understand the effect of various parameters involved in the design of cutout. The simplified solution of cutout analysis in plane shear loads is described in [1 and 4].

II. DESCRIPTION OF THE PROBLEM

The skin stringer panel with cutout considered for the study is shown in Fig. 1 [1]

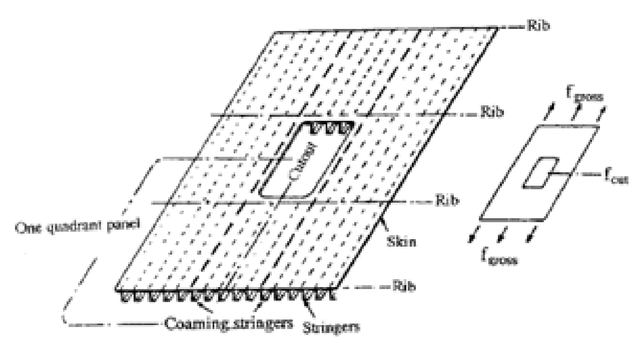

Figure 1: Skin-Stringer panel with cutout

The geometrical dimensions of the panel and stringers are shown in Fig. 2 [1].

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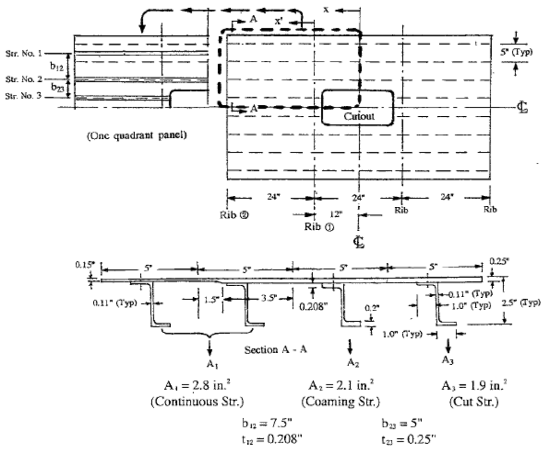

Figure 2: Design parameters of the structure under study

The parameters studied are given in Table 1.

Table 1: Parameters under study and their values

Young's Modulus -E (ksi) =	10500	N/sq.mm	72394.95
Rigidity Modulus - G (ksi) =	4000	N/sq.mm	27579.03
C/S area of Continuous Stringers - A1 (in^2) =	2.8	Sq.mm	1806.448
C/S area of Coaming Stringers - A2 (in^2) =	2.1	Sq.mm	1354.836
C/S area of Cut Stringers - A3 (in^2) =	1.9	Sq.mm	1225.804
Distance b/w centroid of A1 & A2 - b1 (in) =	7.5	mm	190.5
Distance b/w centroid of A2 & A3 - b2 (in) =	5	mm	127
Length of the web with two different thickness l (in) =	5	mm	127
Length of the web till thickness t1 l1 (in) =	1.5	mm	38.1
Length of the web till thickness t2 l2 (in) =	3.5	mm	88.9
Thickness of Contionuous Skin- t1(in) =	0.15	mm	3.81
Thickness of Discontinuous Skin- t2(in) = t23	0.25	mm	6.35
t12 = l/(G*((l1/(t1*G))+(l2/(t2*G))) (in) =	0.208333	mm	5.291667
Half length of cutout = L (in) =	12	mm	304.8

III. ANALYTICAL CALCULATIONS

1. Abbreviations used

A_1 – Cross sectional area of the Continuous stringers
A_2 - Cross sectional area of the Coaming stringers
A_3 - Cross sectional area of the Cut stringers
B_{12} – Distance between the centroids of A_1 and A_2
B_{23} – Distance between the centroids of A_2 and A_3
L_1 and L_2 – Length of webs for thicknesses t_1 and t_2
L – Half length of the cutout
K, K_1, K_2, K_3, K_4 – Parameters dependent on geometry and material properties
E and G – Young's Modulus and Shear Modulus of the material

2. Description of procedure

The structure under study [1] consists of a typical rectangular cutout of a large size reinforced with suitable arrangement of stringers. The cutout under study consists of three types of stringers namely, continuous stringers, cut stringers and coaming stringers (stinger which serves as the stiffener of the cutout). Coaming stringer is designed to have higher moment of inertia to increase its buckling strength and a smaller cross sectional area to reduce and absorb local axial loads caused by the cutout. However, stringer next to the coaming stringer in the cutout area has larger cross sectional area to absorb a portion of the coaming stringer load. In addition, the local skin thickness around the cutout area is also beefed up such that it can redistribute both axial and skin shear loads to the adjacent continuous stringers (A_1) in addition to the coaming stringer (A_2). The panel is sized using 3 stinger methods described in next paragraph.

Three Stringer Method

This panel is sized by the procedure described by the three stringer method [3]. The three stringers are the continuous stringer (with area, A_1), Coaming stringer (A_2) and Cut stringer (A_3).

Rules for adherence in three stringer method

1. The panel in which the cutout is present is assumed to be symmetrical about X (length of the panel in Fig. 1) and Y (width of the panel in Fig. 1) axes. This means that one quadrant can be analyzed and the results can be used in all applicable zones.
2. Along the longitudinal direction, the cross sectional areas of the stringers are constant.
3. If the panel is very long, stringer stresses are uniform at large longitudinal distances from the cutout.

4. Coaming stringer remains as an individual stringer in the substitute structure.

3. Analysis

The effect of change of various parameters listed in Table 1 are studied on the stresses induced in the stringer in a methodical way. The computations are made in excel sheet and the effect of various parameters is plotted and shown in graphical representations. The various results are presented in the next section.

IV. RESULTS AND DISCUSSIONS

The effect of geometry and material is covered by three parameters namely, stress excess factor, stress reduction factor to take care of the change in length of the cutout and a combined factor that accounts for material and geometry effects

a. **Effect of 'K' (depends on material properties and areas of continuous and coaming stringers)**: It is a material parameter that depends on four more material and cross sectional properties. They are defined as follows [2].

$$K = \sqrt{(K_1^2 K_2^2 - K_3 K_4} \text{ .... (1)}$$

$$K_1^2 = \frac{Gt_1}{Eb_1}\left(\frac{1}{A_1} + \frac{1}{A_2}\right) \text{.................. (2)}$$

$$K_2^2 = \frac{Gt_2}{Eb_2}\left(\frac{1}{A_2} + \frac{1}{A_3}\right) \text{................. (3)}$$

$$K_3 = \frac{Gt_2}{Eb_1 A_2} \text{ .... (4)}$$

$$K_4 = \frac{Gt_2}{Eb_2 A_2} \text{ .... (5)}$$

The variation of constant 'K' with respect to different areas of continuous stringers, coaming stringers and cut stringers is shown in Figures 3 to 5. From these graphs it is concluded that as the areas of these stringers is decreased the constant 'K' decreases linearly.

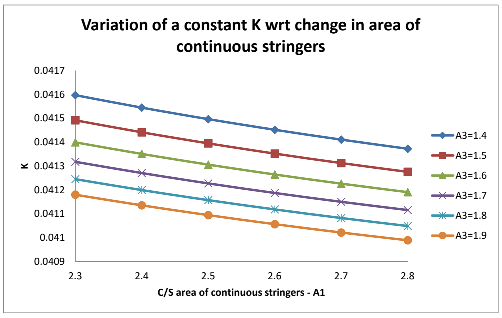

Figure 3: Effect of material and area of Continuous stringers

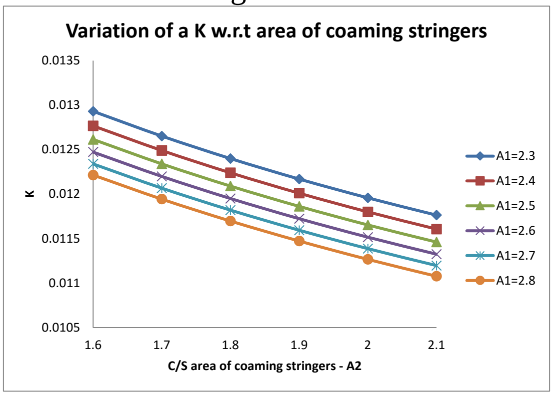

Figure 4: Effect of material and area of Coaming Stringers

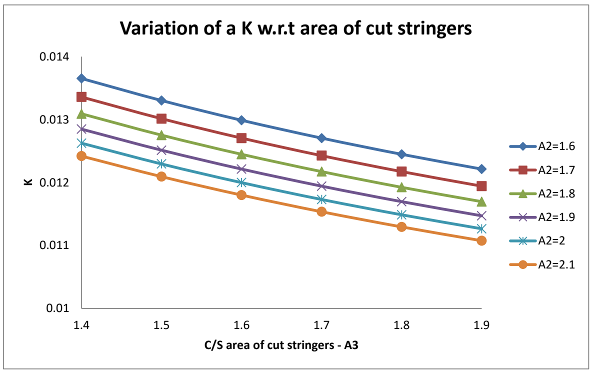

Figure 5: Effect of material and area of Cut Stringers

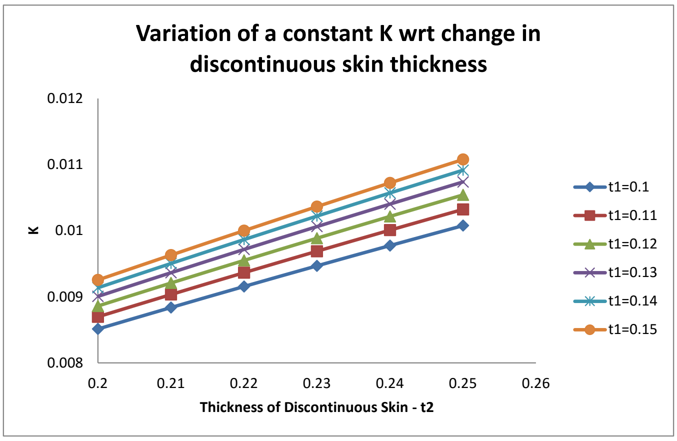

Figure 6: Effect of discontinuous skin thickness

b. **Effect of Discontinuous skin thickness on 'K'**: From Figure 6, it is observed that, as the thickness of the discontinuous skin increases the material-geometric parameter linearly increases.

c. **Effect of discontinuous skin thickness on the geometry-material parameter 'K_1'**: For the coaming stringer, as the cross sectional areas increase, for various values of continuous stringers, the factor 'K_1' decreases (Figure. 7).

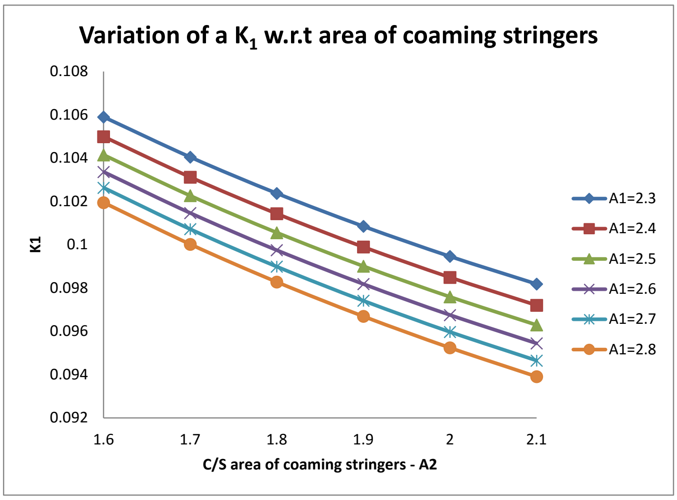

Figure 7: Effect of discontinuous skin thickness

d. Similarly, the study is carried out for various other parameters and are presented in Figure. 8 to Figure. 15. The results are resented in conclusion section.

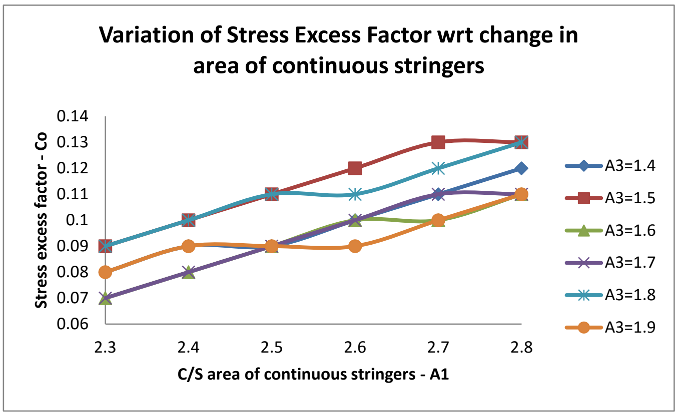

Figure 8: Effect of Continuous Stringers area on Stress Excess Factor

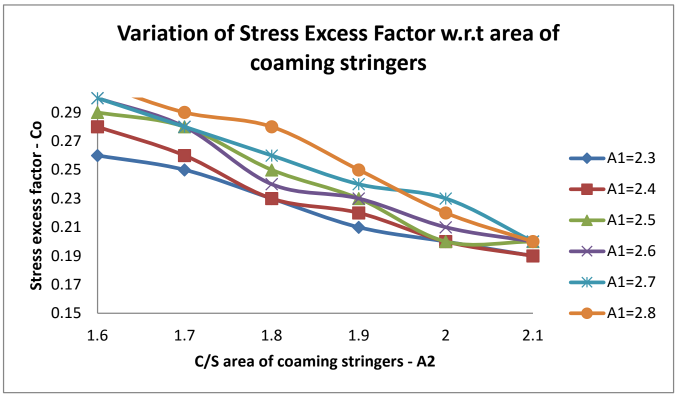

Figure 9: Effect of Coaming Stringers area on Stress Excess Factor

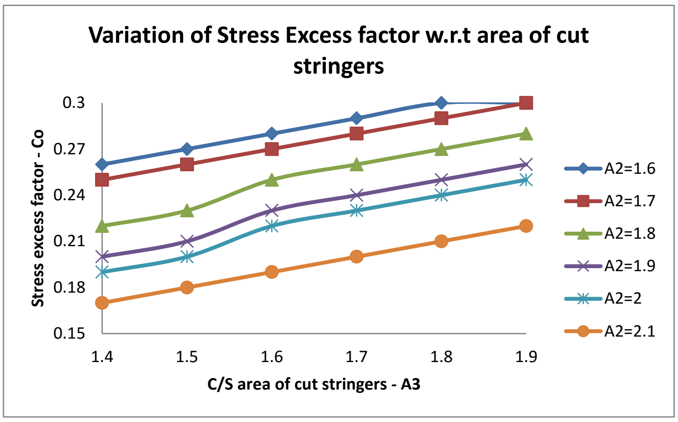

Figure. 10: Effect of Cut Stringers area on Stress Excess Factor

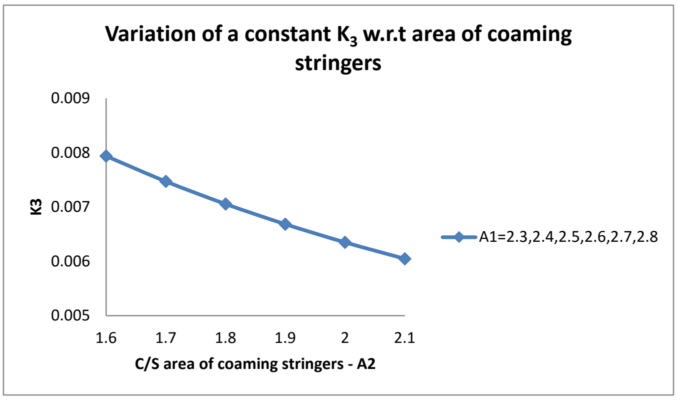

Figure. 11: Effect of Coaming Stringers area on K_3

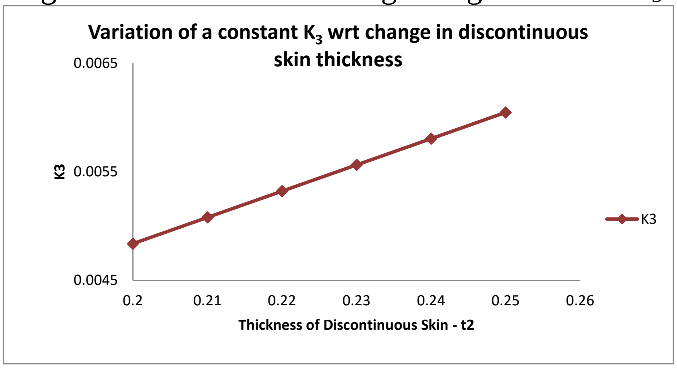

Figure. 12: Effect of thickness of discontinuous skin on K_3

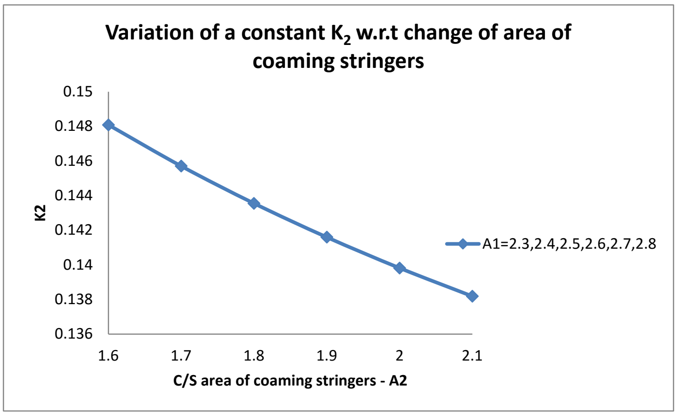

Figure. 13: Effect of Coaming Stringers area on K_2

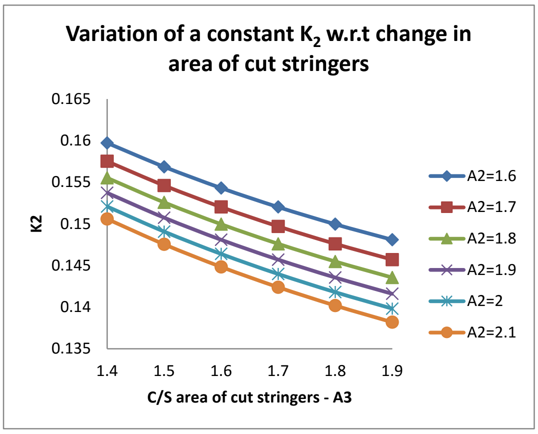

Figure. 14: Effect of Cut Stringers area on K_2

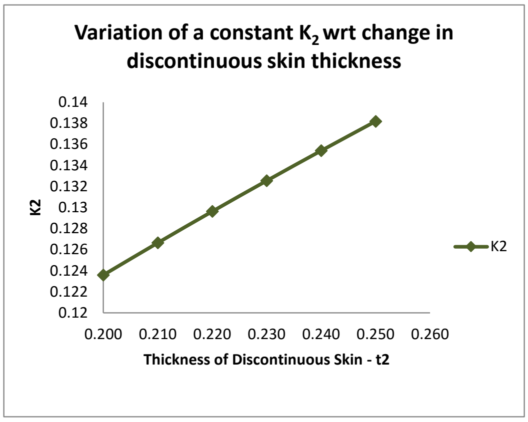

Figure. 15: Effect of thickness of discontinuous skin on K_2

V. CONCLUSIONS

In this paper, some of the factors affecting the strength of the cutout reinforcement are presented. The following conclusions seem to be in order.

a) As the areas of these stringers is decreased the constant ‘K’ decreases linearly.
b) As the thickness of the discontinuous skin increases the constant ‘K’ increases linearly.
c) As the sectional area of the coaming stringer increases, the constant ‘K_1’ decreases linearly.
d) Stress excess factor increases linearly up to a certain value as the areas of continuous stringers increases and thereafter attains a steady value.

e) Stress excess factor decreases nonlinearly as the areas of coaming stringer increases.
f) Stress excess factor increases linearly as the areas of cut stringers increases.
g) The factors K_2 and K_3 decrease as the coaming stringer area increases.
h) The factor K_3 increases as the thickness of discontinuous skin increases.
i) The factor K_2 decreases as the areas of cut stringers increases.
j) The factor K_2 increases as the thickness of discontinuous skin increases.

VI. ACKNOWLEDGMENT

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