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ANALYSIS OF RIVETED JOINT USING VLIEGER/BROEK EQUATION

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ABSTRACT

Aircraft structures consist of largely thin sheets stiffened by different shape of stringers. If damage occurs to the thin sheet, a normal procedure taken is to remove the damage area usually in the shape of rectangular hole which is rounded at the corners to reduce the stress concentration. The area is then reinforced with a repair patch riveted to the sheet. Riveted joint is one of the most methods that are usually used by aircraft manufacturer to repair an aircraft structure. The important thing in analysis of riveted joint is to compute the transfer of load in each of rivet. In this project, the analysis of riveted joint is using finite element method and the stiffness of rivet is calculated by using Vlieger/Broek method.

ABSTRAK

Struktur pesawat terbang terdiri dari sekian banyak pelat yang diperkuat oleh beberapa stringer dengan bentuk-bentuk tertentu. Jika terjadi kerusakan pada struktur tersebut, maka prosedur yang biasa dilakukan adalah dengan membuang bagian yang rusak dengan bentuk segiempat yang tiap sudutnya dibulatkan dengan tujuan agar dapat mengurangi konsentrasi tegangan. Penyambungan dengan paku keling merupakan metode yang paling sering digunakan. Masalah utama pada analisis sambungan paku keling ini adalah menghitung transfer beban yang diterima masing-masing paku keling. Pada penelitian ini, analisis sambungan paku keling menggunakan metode elemen hingga dan harga kekakuan paku keling dihitung menggunakan persamaan Vlieger/Broek.

1. Foreword

Structural damage such as fatigue crack, corrosion, impact damages may occur in aircraft structures during operations. A widely accepted procedure to carry out the repair is to remove the damaged area and reinforce the area with a patch riveted to the structure. In this case, the analysis is divided in two different patch materials. One is using Aluminum material and the other is using GLARE (Glass Reinforced) material [1]. GLARE is one of the composite materials which is consist by fiber layer of Aluminum and prepeg. In the presents work, finite element analysis is performed in analyzing riveted joint using UNA.

2. Current Practice for Aircraft Structural Repair

Before a repair work in an aircraft structure is carried out, the damage has to be first assessed by an engineer or technician. During the assessment a series of inspections and damage evaluation are performed to determine whether a repair work is justified or a structural replacement has to be carried out. If a repair is justified, then the assessment will be focused on the classification of the damage into minor or major repair. A minor repair is usually covered by the "Structural Repair Manual" (SRM) of each type of aircraft, model and manufacturer serial number. If it is not covered by SRM, the engineer can propose a repair scheme.

A basic principle of all repair schemes to a damaged structure is to restore the strength and stiffness of the structure to the level of an intact structure. Some guidelines to achieve the requirements are provided in "*Aircraft Inspection and Repair*", Department of Transportation, Federal Aviation Administration. The guidelines include:

a) Rivets: for rivet replacement, the original size should be used; rivet spacing is three times of the rivet shank or four times of the diameter for two rows application.
b) The distance of the rivet is three times of the diameter itself.
c) The width of the repair patch should be twice of the damaged area.
d) The thickness of the patch material is at least equal to the original material.

The current practice in aircraft structural repair usually leads to a static over-design, which in turn cause a weight penalty [2]. To study the issue of the static over-design, one aspect of repair scheme is considered in the present study i.e. the transfer of load in each of rivet. Figure 1 show the two sheet jointed with six rivets.

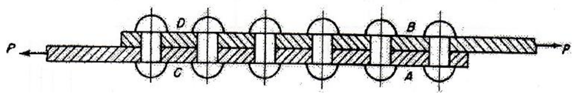

Figure 1. Two sheets jointed with rivets.

For the load transfer scheme in sheet is shown in figure 2. There is by-passing force, F_{BP}, bearing force, F_{BR}, and shear force, F_{FR}. By-passing force is force that transferred to the rivet. Bearing force is force in surface of sheet.

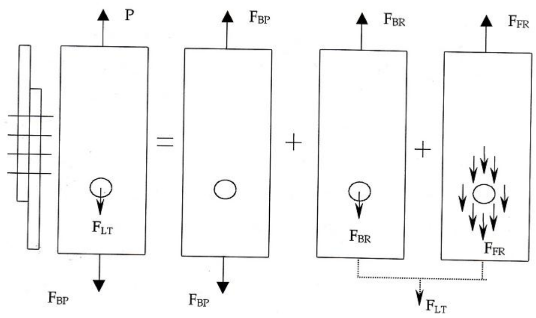

Figure 2. Scheme of load transfer in riveted joint.

3. Finite Element Analysis of Riveted Joint

Load distribution in a row of rivet can be calculated by numerical analysis. The percentage of load transfer in each rivet is depending on the flexibility of rivet itself, and the Vlieger/Broek equation is used in this analysis to calculate the flexibility of rivet.

$$f = \frac{1}{E_r.D}\left[5.0 + 0.8\left(\frac{E_r.D}{E_r.t_s} + \frac{E_r.D}{E_{pc}.t_{pc}}\right)\right] \quad ....(1)$$

where:

f = flexibility
D = rivet diameter
E_r = elastic modulus of rivet
E_s = elastic modulus of sheet/plate
E_{pc} = elastic modulus of patch
t_s = sheet thickness
t_{pc} = patch thickness

The Vlieger/Broek Equation is chosen for the present purpose because it allows the use of different patch thickness and different patch material from the main sheet.

In this report, the analysis is consisting of four models, which is describing in figure 3 - 6.

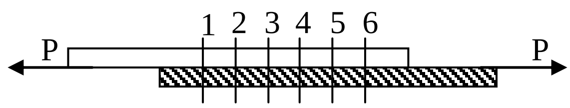

Figure 3. First Model

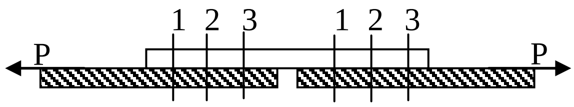

Figure 4. Second Model

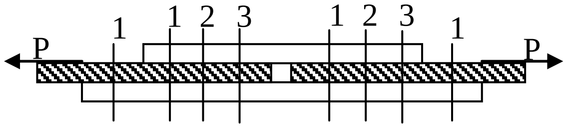

Figure 5. Third Model

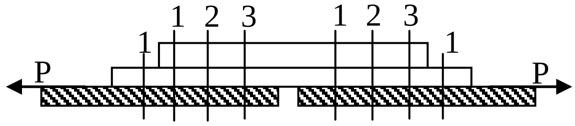

Figure 6. Fourth Model

The finite element analysis was performed by using UNA, "Computer Program for Static and Dynamic Structural Analysis by Finite Element Method", while pre-processing and post-processing software used is FEMAP v6.0. The computation was performed in a personal computer having a clock speed of 900 MHz and Random Access Memory (RAM) of 256 Mb, which give a reasonable running time of only a few minutes for the cases analyzed.

Mechanical properties of the material for the model are defined in table 1.

Table 1. Material Properties

Sheet material (Aluminum 2024-T3)		
w (mm)	t (mm)	E (MPa)
20	1.4	72000
Patch Material (GLARE 3/2)		
20	1.4	58000
rivet		
D (mm)	Pitch (mm)	
4	12	

From equation (1), we have the rivet flexibility, which is perform in table 2.

Table 2. Rivet Flexibility

Sheet Thickness (mm)	Patch Thickness (mm)	Rivet Flexibility (Mpa.mm)
1.4	1.4	28450
1.4	0.7	22221

Element used in modeling the geometry as follows:

1. Quadratic plate element is used to model the sheet and patch. Input required for this element is the thickness.
2. DOF spring element used to model the rivet connecting the main sheet with the patch. This element connects three degrees of freedom of two different nodes, one node on the main sheet and the other on the patch

Below is the procedure of the finite element analysis.

1. Continuum discretization.
2. Divided in to finite element which is the amount of element is contribute the accuracy of output.
3. Choosing displacement model.
4. Displacement, stress and compatibility model for each element.
5. Built the stiffness matrix of each element.
6. Built the global stiffness matrix for model.
7. Boundary condition.
8. Solving.
9. Calculation of stress.

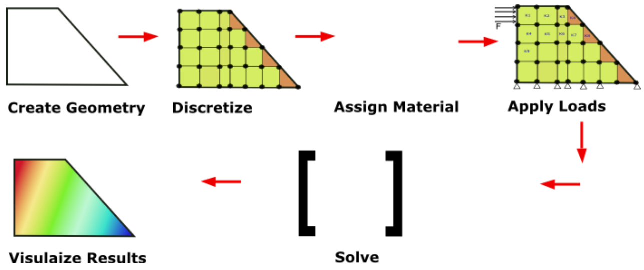

Figure 7. Scheme of finite element procedure.

4. Discussions

For first model, we have the result in table 3, which is show us that by using three, four, five or six rivet, the percentage of load in each rivet is different and it caused by the different of material between sheet and patch.

Table 3. The Percentage of Load Transfer in Each Rivet for the First Model

No. of Rivet	Percentage of load transfer (%)	No. of Rivet	Percentage of load transfer (%)
Three Rivets		Four Rivets	
1	34.275	1	26.975
2	26.825	2	20.025
3	38.9	3	21.55
		4	31.45

No. of Rivet	Percentage of load transfer (%)	No. of Rivet	Percentage of load transfer (%)
Five Rivets			Six Rivets
1	23.325	1	20.875
2	16.45	2	14.3
3	14.3	3	11.425
4	18.375	4	12.05
5	27.575	5	16.4
		6	24.925

In table 3 we can conclude that by using six rivets, the load transfer in each rivet is lower than using three rivets.

In three rivets, each rivet is receiving 33% from applied load, meanwhile four rivets receiving 25% and five rivets receiving 20% and in six rivets, each rivet is receiving 17%.

For second model, the result of load transfer in each rivet is given in table 4.

Table 4. The Percentage of Load Transfer in Each Rivet for the Second Model

No. of Rivet	Percentage of load transfer (%)		No. of Rivet	Percentage of load transfer (%)	
Three Rivets			Four Rivets		
	Left	Right		Left	Right
1	32.375	37.85	1	27.725	32.75
2	29.775	29.775	2	18.875	20.675
3	37.85	32.375	3	20.675	18.875
			4	32.75	27.725

No. of Rivet	Percentage of load transfer (%)		No. of Rivet	Percentage of load transfer (%)	
Five Rivets				Six Rivets	
	Left	Right		Left	Right
1	24.125	28.9	1	21.8	26.325
2	16.025	18.2	2	14.15	16.475
3	12.75	12.75	3	10.3	10.95
4	18.2	16.025	4	10.95	10.3
5	28.9	24.125	5	16.475	14.15
			6	26.325	21.8

From table 4, we can see that by using six rivets the load transfer is lowest than others its about 26 % and for five rivet is 29 %, for four rivet is 33 % and 38 % for three rivet.

In the third model, the result is given in table 5, the percentage of load transfer in each rivet is calculated for three variations, which is:

a) Variation 1 : 1 rivet in end of sheet and 3 rivets in the middle.
b) Variation 2 : 1 rivet in end of sheet and 4 rivets in the middle.
c) Variation 3 : 2 rivet in end of sheet and 4 rivets in the middle.

Table 5. The Percentage of Load Transfer in Each Rivet for the Third Model

No. of Rivet	Percentage of load transfer (%)		No. of Rivet	Percentage of load transfer (%)	
Variation 1			Variation 2		
	Left	Right		Left	Right
1	27.75	28.55	1	24.05	24.05
patch (under)			patch (under)		
1	8.15	10.2	1	7.2	10.075
2	7.575	7.325	2	5.95	6.95
3	10.375	7.775	3	6.95	5.95
patch (above)			4	10.075	7.2
1	18.875	12.975	patch (above)		
2	14.25	14.25	1	14.15	11.35
3	13.025	18.925	2	10.6	9.7
			3	9.7	10.6
			4	11.35	14.15

For the third variation, the percentage of load transfer in each rivet is shown in the table below:

No. of Rivet	Percentage of load transfer (%)				
Variation 3			Patch (above)		
	Left	Right		Left	Right
1	19.35	12.2	1	13.6	11.075
2	12.175	19.35	2	10.3	9.5
Patch (under)			3	9.5	10.3
1	4.45	9.425	4	11.075	13.6
2	4.225	5.9			
3	5.9	4.225			
4	9.425	4.45			

We see that in the third model, critical load in end of sheet position (19,35 %) is less than in the second model (21,8 %), the differences is about 4,7 %.

The next model we will discuss is double patch as seen in the figure 5. The result is shown in table 6.

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Table 6. Load Transfer of Model 4.

No. of Rivet	Percentage of load transfer (%)		No. of Rivet	Percentage of load transfer (%)	
Variation 1			Variation 2		
	Left	Right		Left	Right
1	31.8	31.825	1	29.5	27.25
patch (under)			patch (under)		
1	21.125	25.6	1	17.1	21.025
2	21.475	21.675	2	15.775	17.325
3	25.6	20.9	3	16.95	16.35
patch (above)			4	20.7	18.025
1	15.225	6.8	patch (above)		
2	11.025	10.925	1	12.775	5.675
3	6.8	15.3	2	9.975	7.775
			3	7.7	9.975
			4	5.6	12.625

No. of Rivet	Percentage of load transfer (%)				
Variation 3			Patch (above)		
	Left	Right		Left	Right
1	22.875	16.775	1	13.35	5.4
2	16.775	22.875	2	10.075	7.575
Patch (under)			3	7.575	10.075
1	13.125	19.15	4	5.4	13.35
2	13.1	15			
3	15	13.1			
4	19.15	13.1			

From the table 6, we can see that for rivet in the end of sheet, load transfer in variation 3 is less than in variation 2 with the differences is about 6,6 %. And for the rivet in patch (above) is getting lower for the position of rivet moving to the middle.

From the result that shown in table 3 through 6, we can conclude that the differences of double patch (under and above of plate) and double patch (two layers in above of plate) is:

1) Maximum load transfer in end of plate in double patch (under and above of plate) is lower than double patch (two layers in above of plate).
2) The distribution of load transfer in double patch (under and above of plate) is less than double patch (two layers in above of plate).

5. Concluding Remarks

1. More rivets we use, the load transfer of each rivet is getting smaller.
2. The value of flexibility of rivet is contributed by the diameter of its rivet.
3. The greater the thick of patch we use, the differences of load transfer in each rivet is getting higher.
4. The distribution of load transfer for single lap joint is greater than the double patch joint.

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