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Research paper

Multi-configuration Stiffened Panels under Compressive Load: Part 1 – Theoretical Analysis

Ramzyzan Ramly[1*], Wahyu Kuntjoro[2], Amir Radzi Abdul Ghani[3], Rizal Effendy Mohd Nasir[4], and Zulkifli Muhammad[1]

[1]*Faculty of Mechanical Engineering, Universiti Teknologi MARA 40450 Shah Alam Selangor Malaysia*
[2]*Aviation Technology Research (ATR) Faculty of Mechanical Engineering, Universiti Teknologi MARA Shah Alam Selangor Malaysia*
[3]*Automotive Research & Testing Centre (ARTeC), Faculty of Mechanical Engineering, Universiti Teknologi MARA Selangor Malaysia*
[4]*Flight Technology & Test Center (FTTC), Faculty of Mechanical Engineering, Universiti Teknologi MARA Selangor Malaysia*
** Corresponding author E-mail :ramzyzan@salam,uitm.edu.my*

Abstract

Stiffened panels are the structure used in the aircraft wing skin panels. Stiffened panels are often critical in compression load due to its thin structural configuration. This paper analyzes the critical loads of a multi configuration stiffened panels under axial compressive loading. The study comprised three main sections; theoretical analysis, numerical analysis and experimental analysis. The present paper deals only with the theoretical analysis. This first part of analysis is very important since the results will be the main input parameter for the subsequent numerical and experimental analysis. The analysis was done on the buckling properties of the panels. Four panel configurations were investigated. Results showed that even though the stiffened panels have the same cross-sectional area, their critical loads were not identical.

Keywords: *critical loads, multiconfiguration stiffened panels, theoretical analysis, moment of inertia*

1. Introduction

The objective of the study is to investigate the critical load of the multi configuration stiffened panels under axial loads. Stiffened panels are widely used in structures especially in vehicle such as aircraft, ship, high-speed train, steel bridges, and multi-segmented road vehicles. This study however, emphasizes on aircraft structures, where stiffened panels are widely used in the bulkhead of aircraft fuselage and the wing skins and wing ribs. The present research focuses on the wing upper skin panels since the upper skin panels experience compression loads while the lower skin panels experience more tensile loads. The successive part of the study will be an experimental study with embedded sensors. The next step of the study follows the preceding research described in [1]. The research also involves experimental and numerical approach similar to literatures [2, 3]. In various experiments, different stiffener types were tested until failure to understand their performance [3, 4]. An experimental study involving the design, analysis, fabrication and testing of grid stiffened panels for aircraft structures revealed that the damage tolerance in the aircraft structure design increased but the weight had been reduced [5]. However, the study was done on composite structures. A finite volume analysis on the buckling of stiffened curved panels under axial compressive loadings was also conducted [6], although the research focused on steel bridges. Nevertheless, these results can be used as a guideline for this research.

The critical load is very much related to the axial compression and the test is very relevant to the stiffened panel structures. If the axial load exceeds the critical load, the structures tends to buckle. This buckling formula however, is applicable to the column or slender plates [7, 8] but the same formula may also be applied on stiffened panels. The critical load formula is as follows:

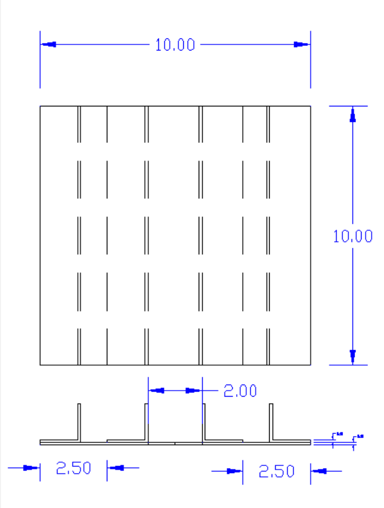
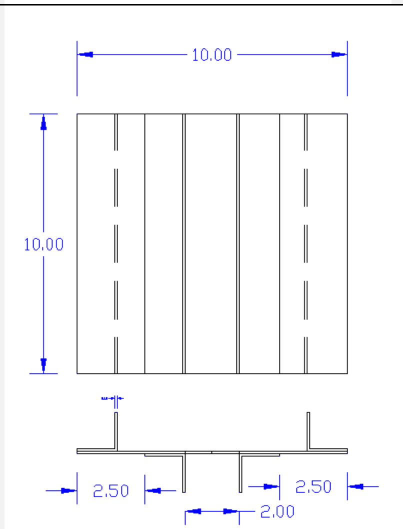
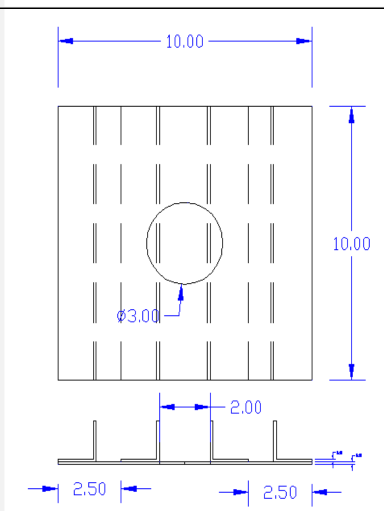
$$P_{cr} = \frac{\pi^2 EI}{KL^2} \tag{1}$$

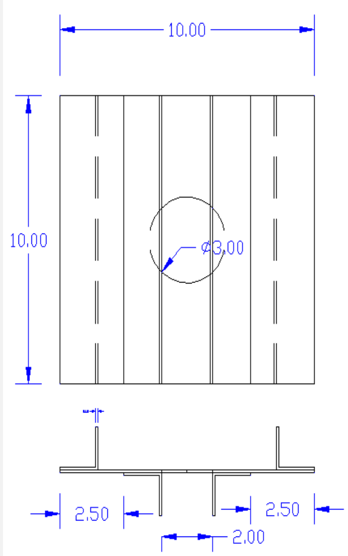
where P_{cr} is the critical axial load, E is the modulus of elasticity, or Young's Modulus (for aluminum alloy, the Young's Modulus is approximately equals to 70 GPa or $70\text{x}10^{-9}$ N/m^2), I is the moment of inertia, and L is the effective length of the column. The structure is assumed as pinned-pinned condition, with K equals to 1.0.

2. Methodology

The research is divided into three methods namely theoretical, numerical (Finite Element Method) and experimental. The specimen analyzed in the research was a stiffened panel in different configurations. There were four cases altogether. The four specimens were of the same cross-sectional area at the face of axial compression, but with different moment of inertia, I. Two of the specimens were of perfect structures while the other two specimens had holes of about 30 cm diameter at the center of the panels. The specimens were made of Aluminum Alloy 2024-T3 of 10.0 cm by 10.0 cm size. The panels were stiffened by a L-shaped stiffener which were made of the same material as the panel and had dimensions of 1.5 cm by 1.5 cm. The stiffener and the skin were joined together using blind rivets of 2.5 mm shank diameter. Table 1 shows the configuration and properties of the specimens.

Table 1. Configuration of the specimen

Specimen	Configuration	Properties and descriptions
I		The specimen is 100 mm x 100 mm x 1 mm. Four L-shaped stiffeners are attached to one side of the panel. The stiffener is 115 mm x 15 mm x 1 mm attached to the panel using 2.5 mm diameter blind rivets. A = 2.16×10^{-4} m^2 I_{XX} = 3.704×10^{-9} m^4 I_{YY} = 1.862×10^{-7} m^4
II		The specimen is 100 mm x 100 mm x 1 mm. Two L-shaped stiffeners are attached on each side of the panel using 2.5 mm diameter blind rivets. A = 2.16×10^{-4} m^2 I_{XX} = 5.034×10^{-9} m^4 I_{YY} = 1.862×10^{-7} m^4
III		The specimen is 100 mm x 100 mm x 1 mm. There is a hole of about 30 mm in diameter at the center of the panel. Four L-shaped stiffeners are attached to one side of the panel using 2.5 mm diameter blind rivets. Both ends properties: A = 2.16×10^{-4} m^2 I_{XX} = 3.704×10^{-9} m^4 I_{YY} = 1.862×10^{-7} m^4 At the center of the panel properties: A = 1.48×10^{-4} m^2 I_{XX} = 2.048×10^{-9} m^4 I_{YY} = 5.366×10^{-6} m^4

IV		The specimen is 100 mm x 100 mm x 1 mm. There is a hole of about 30 mm diameter at the center of the panel. Two L-shaped stiffeners are attached on each side of the panel using 2.5 mm diameter blind rivets. Both ends properties: $A = 2.16\times10^{-4}\,m^2$ $I_{XX} = 5.034\times10^{-9}\,m^4$ $I_{YY} = 1.862\times10^{-7}\,m^4$ At the center of the panel properties: $A = 1.48\times10^{-4}\,m^2$ $I_{XX} = 2.737\times10^{-9}\,m^4$ $I_{YY} = 5.494\times10^{-7}\,m^4$

The orientation axis of the specimen is shown in Fig 1. The specimen is loaded as shown in Fig 2.

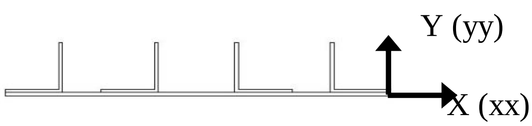


Fig 1: Orientation axis for the purpose of calculation the moment of inertia.

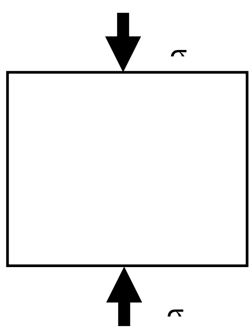


Fig. 2: Axial compression of the stiff-

After the cross-sectional area and the moment of inertia were established, the critical load can be found for each configuration using Equation 1. The following Equation 2 calculates the critical stress at the critical load.

$$\sigma_{cr} = \frac{P_{cr}}{A} \tag{2}$$

where, σ_{cr} is the stress in N/m2 and A is the effective cross-sectional area of the specimen in m^2.

3. Results and Discussion

From both Equation 1 and Equation 2, and using data from Table 1, results for critical load, P_{cr}, and critical stress, σ_{cr}, are calculated and tabulated in Table 2.

Table 2: The resultant critical load, P_{cr}, and critical stress, σ_{cr}.

Case	I_{xx} (m^4)	I_{yy} (m^4)	Cross-Sectional Area (m^2)	P_{cr}, about x (N)	P_{cr}, about y (N)	σ_{cr}, about x (N/m^2)	σ_{cr}, about y (N/m^2)
I	3.704E-09	1.862E-07	2.160E-04	2.559E+05	1.286E+07	1.185E+09	5.956E+10
II	5.034E-09	1.862E-07	2.160E-04	3.478E+05	1.286E+07	1.610E+09	5.956E+10
III A	3.704E-09	1.862E-07	2.160E-04	2.559E+05	1.286E+07	1.185E+09	5.956E+10
III B	2.048E-08	5.366E-06	1.480E-04	1.415E+06	3.707E+08	9.560E+09	2.505E+12
IV A	5.034E-09	1.862E-06	2.160E-04	3.478E+05	1.286E+08	1.610E+09	5.956E+11
IV B	2.737E-09	5.494E-07	1.480E-04	1.891E+05	3.796E+07	1.278E+09	2.565E+11

Data form Table 2 is plotted to compare the results as shown in Fig 3. a, b, c, and d.

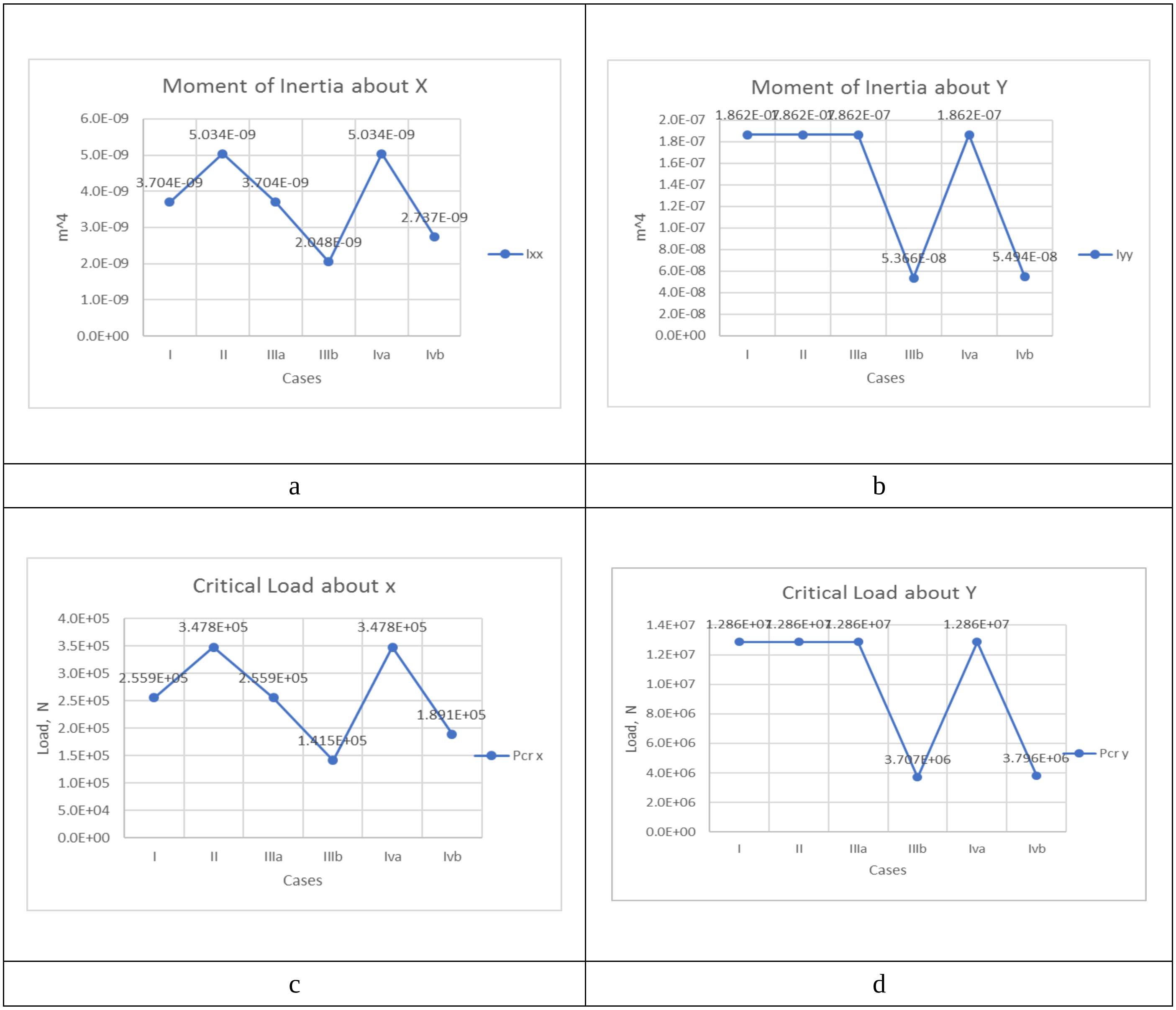


Fig. 3. Graphs of comparison of (a) moment of inertia about x, (b) moment of inertia about y, (c) critical load about x, and (d) critical load about y

Fig. 3 showed that the stiffened panels will fail at the lowest moment of inertia, with the lowest critical load. Between the moment of inertia of x and moment of inertia of y, it was found that the lowest moment of inertia was 2.048E-9 m^4, which correspond to the lowest critical load of 1.415E5 N. This would be the maximum load to be applied when doing the experiment at the later stage.

4. Conclusion

This paper presented a partial study of the present research which is the theoretical analysis. Results obtained from this analysis will be used for the subsequent study of the finite element analysis.
Experimental studies can be done using fiber Bragg grating sensors and strain gauge sensors.

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