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Buckling Analysis of Stiffened Panels of Variable Angle Tow

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Abstract—*Modern aircraft wings are thin walled structures made of ribs, spars and stiffened panels and top skin. In flight the top skin is subjected to high compressive force that can cause buckling instability. The manufacture of advanced stiffened panels with variable tow angles can lead to panels with flat profile on one side and smooth curved profile on other side. In this paper we attempted to design stiffened panels with variable angle tow and also with flat and curved profile. An FEA model is generated and an analysis is made to investigate the effect of stress concentration and buckling behavior of panels of variable angle tow (VAT). Also designs of symmetric VAT panels and asymmetric VAT panels are generated and analyzed. Based on the analysis models of stiffened panel which have increased strength on buckling performance are proposed.*

Keywords: *Buckling, stiffened panel, symmetric and asymmetric VAT, stress concentration*

1. INTRODUCTION

Aircraft structural systems are thin-walled structures with wing structure composed of ribs, spars and stiffened panels. For civil aircraft, the top skin is, under aerodynamic loading, subject to axial compressive forces that can cause buckling instability. Typically these stiffened panels can have a considerable postbuckling reserve of strength, enabling them to remain in stable equilibrium under loads in excess of their critical buckling load, provided the initial buckling mode is a local one.

Aircraft wing components and fuselage components are joined, in metallic structure, by means of riveting (and more recently welding) to form complete wing and fuselage structure. For stiffened panel construction components can be machined integrally. Single piece stiffened panels have several potential advantages that include cost savings through reductions in assembly labour, tooling, part count and manufacturing time.

Stiffened panels are commonly used on aircraft as primarystructures such as wing covers and fuselage panels . Stiffenedpanels typically consist of a plate braced by longitudinal stiffenersand are an efficient conFig. uration for carrying compressive loads, particularly when buckling is a design driver as is the case for aircraftwing covers.

A stiffened panel can fail via a variety of mechanisms including skin-stiffener debonding material strength failure and buckling. Buckling failure predominantly occurs in one of two modes as shown in Fig. . 1; local, where thestiffeners act as ‘panel breakers’ forcing the skin to buckle locallybetween the stiffeners and global, where both plate and stiffeners buckle out-of-plane. Confining the buckling mode to be local is preferential to global as it, in general, leads to lighter designsand greater post-buckling stiffness. The local mode’s higher post-buckling stiffness is due to the unbuckled stiffeners carryingload in the post-buckling regime.

Buckling of stiffened panels has received considerable attentiondating as far back as 1921 by Timoshenkowho used the Ritzmethod to analyze isotropic longitudinally and transversely stiffenedplates subject to compression, shear and bending. Continuedinterest in this field has seen many publications in the past centurywith current research focussing heavily on composite stiffenedpanels. Local buckling analysis methods can be split intothree categories based on the consideration of the stiffener.Thefirst method treats the stiffener as a simple support which facilitatesfast closed-form solutions to be obtained but assumes nulltorsional restraint and hence underestimates the buckling load.

The second method models the torsional restraint by replacingthe stiffener blade with an equivalent torsional spring or beamattached to the skin’s midplane. This method is often sufficientlysimple to obtain accurate closed-form solutions, howeveris strictly only valid for an unloaded stiffener and assumes no stiffenerblade buckling or warping. Correction factors reducing theeffective restraint in the case of an axially applied load to the stiffener have been proposed and provide improved solutions whenload is carried by the stiffener . The third method modelsboth the skin and stiffener as platesallowing local bucklingmodes of the stiffener and the interaction between the skinand stiffener to be captured. This higher fidelity approach has anincreased computational cost but provides a more robust solutionthan the elastic restraint method.

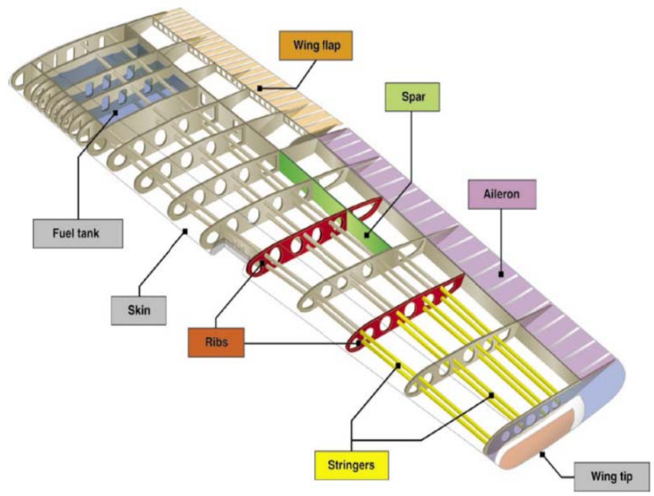


Fig. 1: Components of wing.

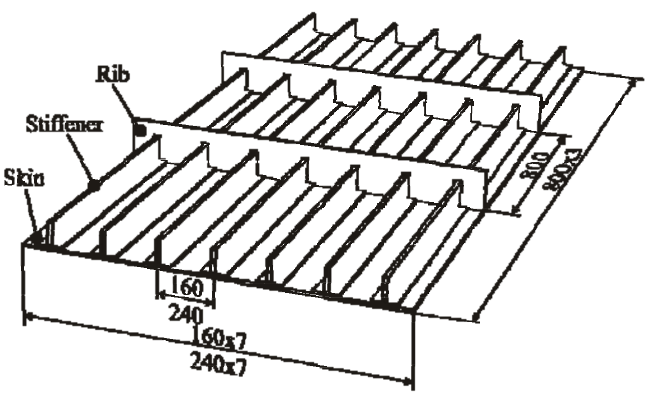


Fig. 2: T stiffener panel .

2. CONSTRUCTION OF STIFFENED PANEL

Stiffened panels are the longitudinal members of the wing which under take most of the compressive loads. The most commonly used stiffened panel in aircraft wing structures are T-type panels. The T-type panels consists of a vertical member called stiffeners and a horizontal member called subpanel. Due to compressive loads they are subjected to buckling. The factors affecting the buckling performance of a stiffened panel are (1) length to width ratio (2) Stiffener geometry and spacing (3) Aspect ratio of the plate between stiffener (4) Plate slenderness (5) Residual stress (6) Initial distortions (7) Boundary conditions (8) Type of loading.

Among the above factors the stiffener geometry and spacing (2) compensates the more for buckling instability of the structure. Hence we attempted to analyze the stiffened panel of variable stiffener geometry and spacing. The design consists of symmetric and asymmetric tow angled stiffened panels of dimensions as tabulated below.

S. no	Dimension of stiffened panel (length X width X thickness) in mm	Left hand side tow angle in degree	Right hand side tow angle in degree
1	275×152.77×10	0	0
2	275×152.77×10	1.5	1.5
3	275×152.77×10	3.0	3.0
4	275×152.77×10	4.5	4.5
5	275×152.77×10	6.0	6.0
6	275×152.77×10	7.5	7.5
7	275×152.77×10	0	1.5
8	275×152.77×10	0	3.0
9	275×152.77×10	0	4.5
10	275×152.77×10	1.5	3.0
11	275×152.77×10	1.5	4.5
12	275×152.77×10	3.0	4.5

The designs of the above are generated using material of Aluminium alloy with Young's modulus E = 71Gpa, Density = 2700 Kg/m^3 and Poisson's ratio = 0.33.

3. FINITE ELEMENT MODELING AND BUCKLING ANALYSIS

Different finite element modeling approaches and boundary conditions are analyzed for the stiffened Aluminium alloy panels to achieve the best accuracy with an acceptable computational time in optimization process.For this purpose T stiffener aluminium panel as dimensions tabulated in above are used. To investigate the buckling behavior of these panels nearly 12 finite element models are developed with ANSYS using tri-angular node element conFig. uration.

Possible failure modes of stiffened panel under longitudinal compression are as follows:

(1) Plate buckling and ultimate collapse – it means that the maximum plate load is exceeded and is followed by unloading of the plate, loading to collapse of the stiffened panel before significant yield occurs in the stiffener. (2) Inter frame flexural buckling – this type of failure involves yielding of the stiffener which is accelerated by loss of stiffness due to buckling or yielding of the plate. (3) Restrained torsional buckling of stiffener - it is due to elastic or elasto-plastic loss of stiffness depending on the slenderness of the stiffener, the rotational restrained provided by the plating and the initial out of shape. (4) Overall grillage buckling – it involves bending of transverse griders as well as longitudinal stiffness.

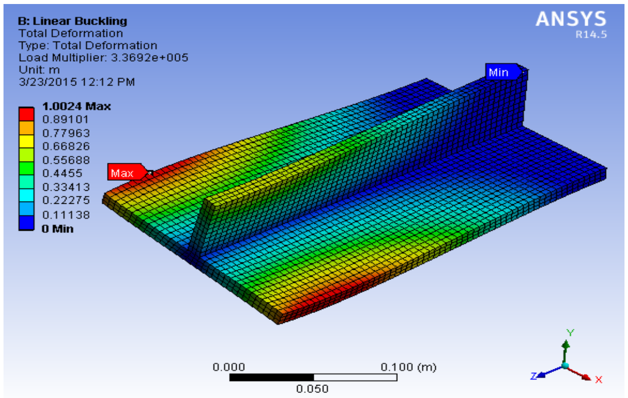
4. RESULT AND VALIDATION

The Stiffened panels constructed as per the above dimensions and variable tow angles are analyzed for their buckling performance and the obtained results are as follows:

4.1 Symmetric VAT

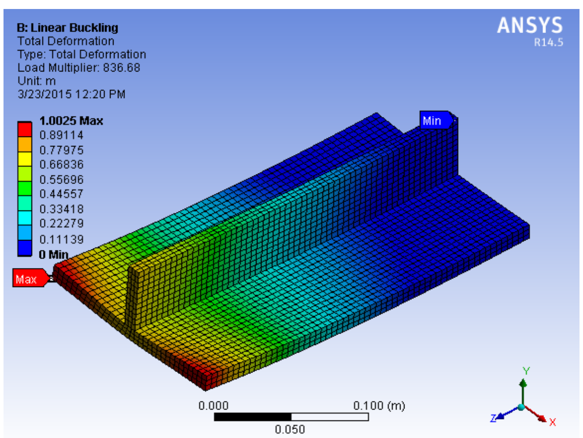
Dimensions : (275×152.77×10) & α = 0˚

Max. Deformation = 1.0024 mm



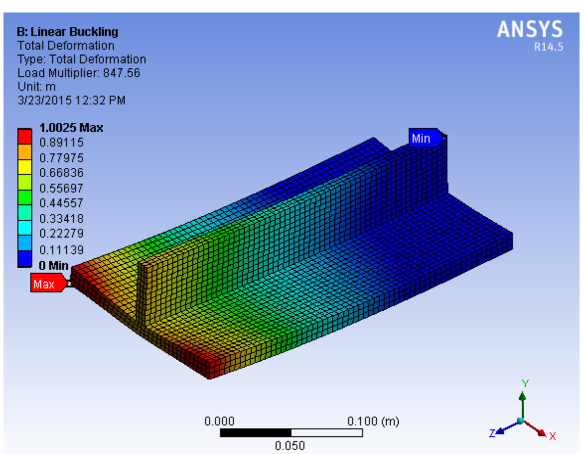
Dimensions : (275×152.77×10) & α = 1.5˚

Max. Deformation = 1.0024 mm



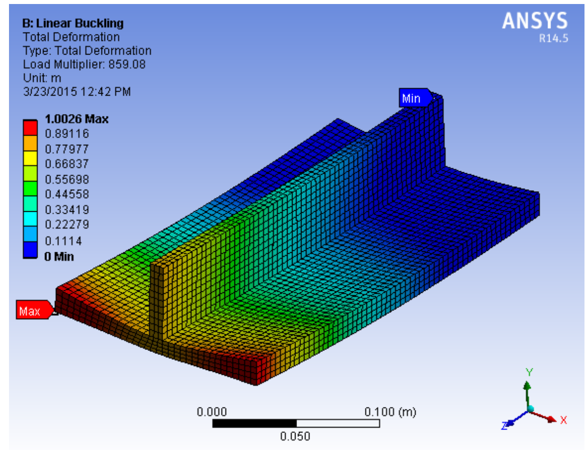
Dimensions : (275×152.77×10) & α = 3.0˚

Max. Deformation = 1.0025 mm



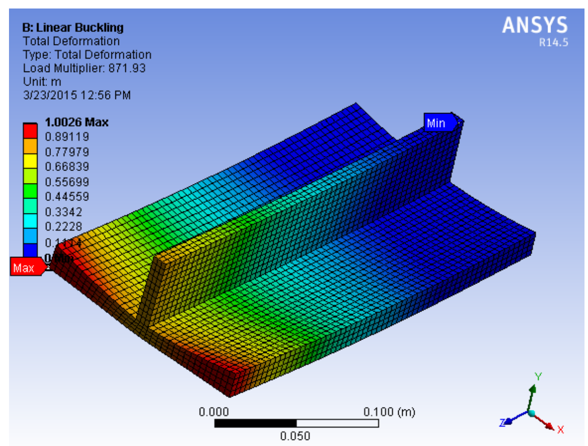
Dimensions : (275×152.77×10) & α = 4.5˚

Max. Deformation = 1.0026 mm



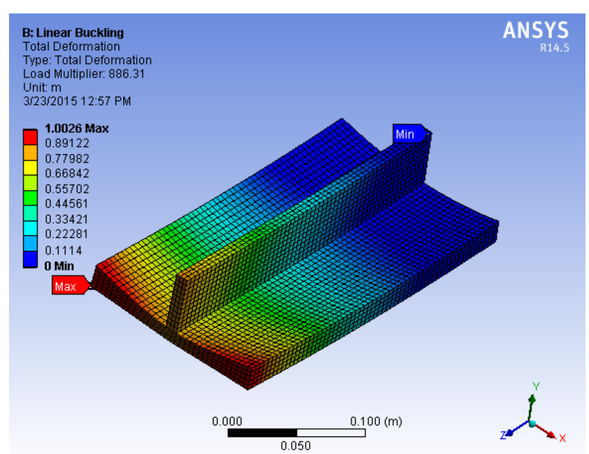
Dimensions : (275×152.77×10) & α = 6.0˚

Max. Deformation = 1.0026 mm



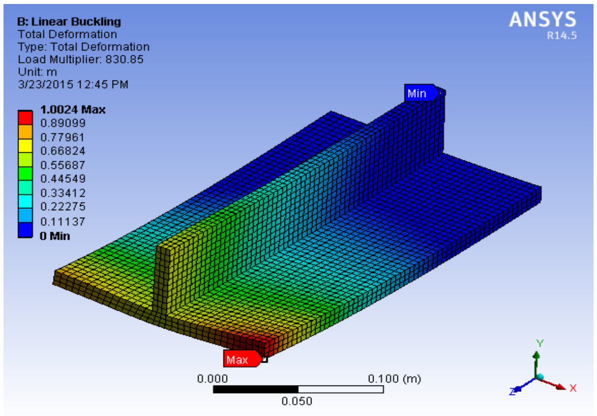
Dimensions : (275×152.77×10) & α = 7.5˚

Max. Deformation = 1.0026 mm

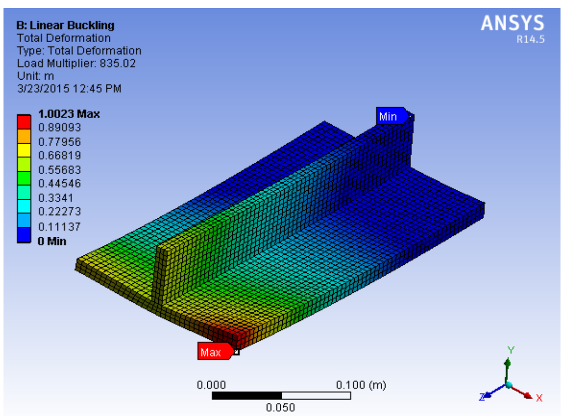


4.2 Asymmetric VAT

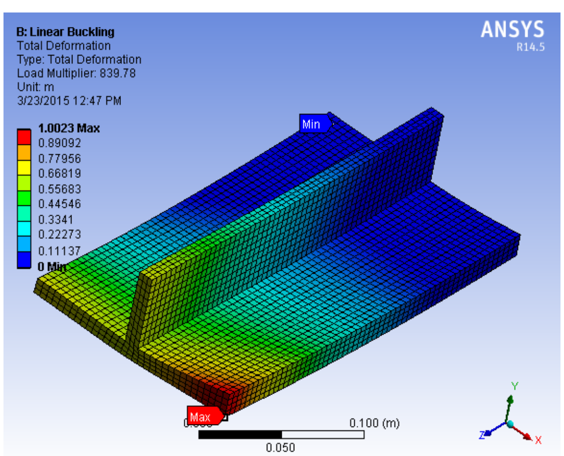
Dimensions:(275×152.77×10)α_1=0˚,α_2=1.5˚Max. Deformation = 1.0024 mm



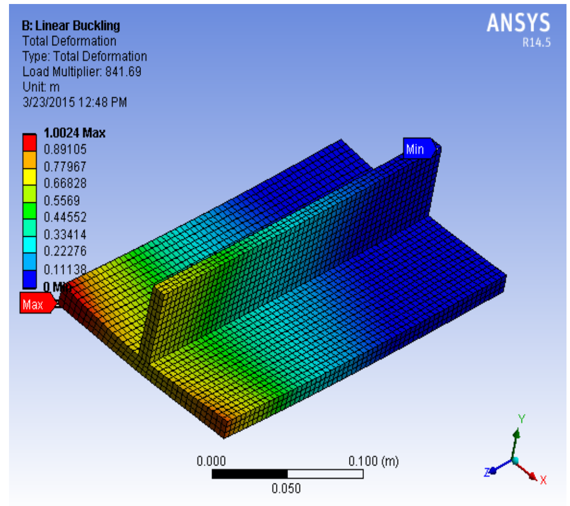
Dimensions:(275×152.77×10)α_1=0˚,α_2=3.0˚Max. Deformation = 1.0023 mm



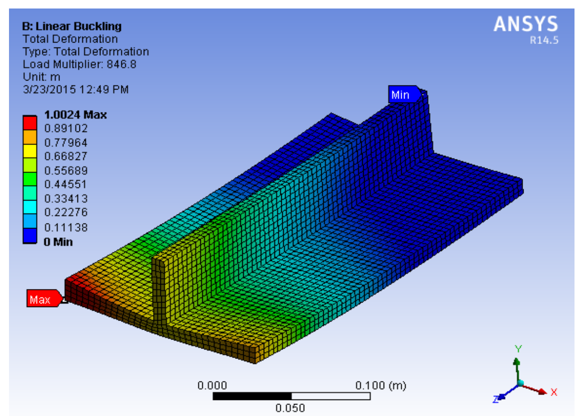
Dimensions:(275×152.77×10)α_1=0˚,α_2=4.5˚Max. Deformation = 1.0023 mm



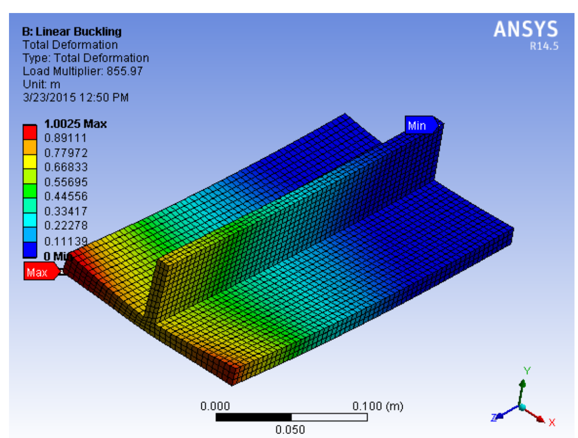
Dimensions:(275×152.77×10)α_1=1.5˚,α_2=3˚Max. Deformation = 1.0024 mm



Dimensions(275×152.77×10)α_1=1.5˚,α_2=4.5˚Max. Deformation = 1.0024 mm



Dimensions:(275×152.77×10)α_1=3˚,α_2=4.5˚Max. Deformation = 1.0025 mm



5. CONCLUSION

On validating the results in this work the least deformation obtained for symmetric panels is 1.0024mm for $\alpha = 0^\circ$ and for asymmetric panels is 1.0023mm for $\alpha_1=0^\circ,\alpha_2=3.0^\circ$ and $\alpha_1=0^\circ,\alpha_2=4.5^\circ$. Hence we propose a model of asymmetric stiffened panel with tow angles $\alpha_1=0^\circ,\alpha_2=3.0^\circ$ has gave the better buckling performance for the aircraft wing structure.

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