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Evaluation of Buckling Stability of the Front Spar in an Aircraft Wing

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***Abstract*—Wing spars are basically the members that carry bending loads acting on the wing. Buckling failure of Spar web is a common problem associated with most of the wing designs. In this research, buckling stability of the spar is verified through both Classical and Finite element approaches. The location critical to buckling was identified and Critical Eigen value was obtained. Also the critical buckling mode shape is studied for further design modifications. The detailed geometry of the Spar is modeled using CATIA; Finite element model of the Spar was generated in MSC Patran and analyzed in MSC Nastran.**

***Keywords*—Buckling, Buckling stability, Bending, Eigen value, Finite Element approach**

INTRODUCTION

Spars are the main members of the wing. They extend lengthwise of the wing (crosswise of the fuselage). The entire load carried by the wing is ultimately taken by the spars. In flight, the force of the air acts against the skin. From the skin, this force is transmitted to the ribs and then to the spars. Most wing structures have two spars, the front spar and the rear spar. The front spar is found near the leading edge while the rear spar is about two-thirds the distance to the trailing edge.

The function of spar web is to resist the shearing forces between the spar caps and to hold the spar cap on the compression side of the spar in column so that it doesn't buckle.

PROBLEM STATEMENT

Wing Spar is a critical component in wing structure which plays a key role in the structural integrity of the wing. The objective of this paper is to study the buckling behavior of the spar under lift load.

The detailed specifications of the aircraft considered and magnitude of estimated loads are specified hereunder.

Category:	Light Aircraft
Total weight of the aircraft:	18.76kN
Lift load on wing:	45.03kN
Load on each wing:	22.5kN
Load on front spar:	16.9kN
Total length of spar:	3600 mm
Wing span:	8000mm
Aspect ratio:	6.0
Taper ratio:	0.50

The finite element model of spar need to be analyzed and critical buckling factors need to be obtained. The critical value obtained from finite element approach is verified through plate buckling formulae.

BUCKLING ANALYSIS

The major goal here is to verify whether the current design is safe under anticipated buckling loads. For this, Eigen value buckling analysis of the model is carried out in MSC Nastran. The flowchart of the procedure followed is shown in Fig.1

The various steps followed during the buckling analysis are shown hereunder.

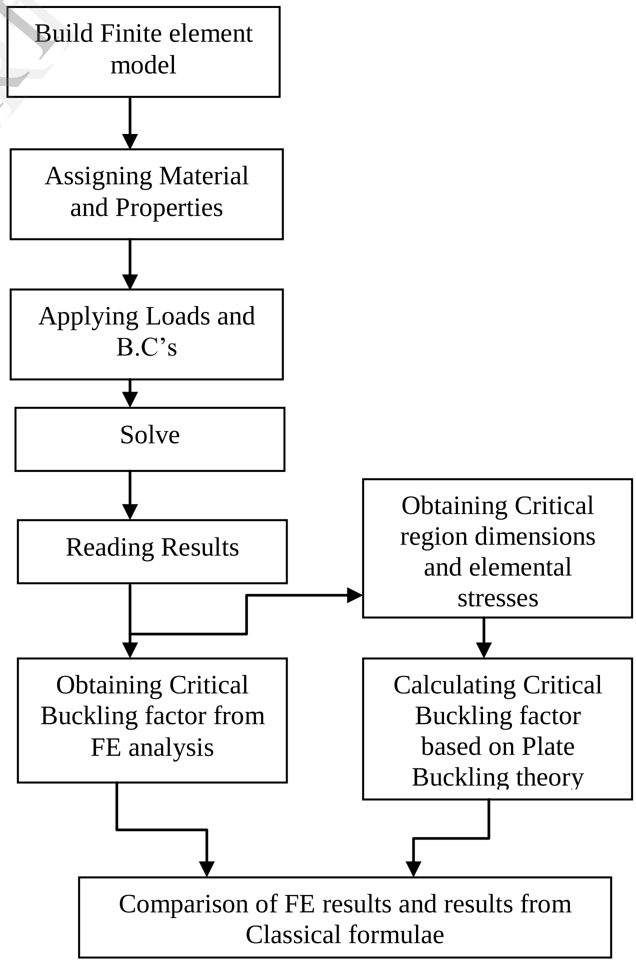

Fig.1 Block Diagram for Buckling analysis

The material used for both Spar web and Spar caps is Aluminium alloy 2024-T3.The material properties used are listed hereunder:

Properties	Values
Elastic modulus	73000 N/mm^2
Poisson's ratio	0.33
Density	2.77 g/cm^3
Yield stress in tension	275 N/mm^2

Table.1 Material Properties

The loads are applied at eight different stations along the length of spar based on data from Ref [1] as shown in Table 2.

Station no.	Span (mm)	Dimensionless span wise coordinate	Loading coefficient	Force(N)
1	450	1.25	1.28	2510.51
2	900	2.50	1.24	2432.05
3	1350	3.75	1.16	2275.15
4	1800	5.00	1.08	2118.24
5	2250	6.25	0.97	1902.49
6	2700	7.50	0.84	1647.52
7	3150	8.75	0.64	1255.25
8	3600	10.00	0.10	196.13

Table.2 Spanwise Loads

These calculated loads are applied on the finite element model and constraints were applied at the root as well as at different stations as shown in Fig.2

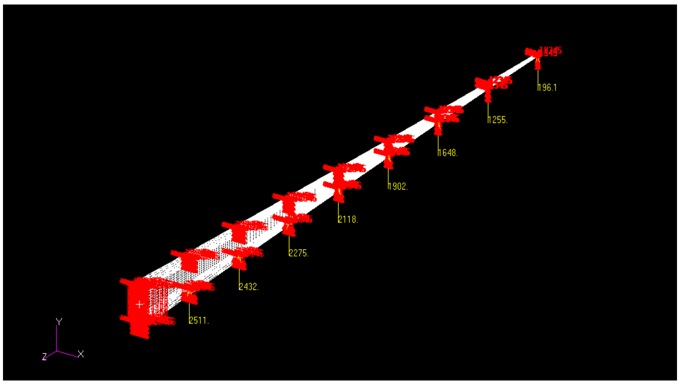

Fig.2 Finite Element Model of Spar

RESULTS AND DISCUSSIONS

The results of the Eigen value buckling analysis points out that the spar is safe in buckling. It identifies an Eigen factor of '10.51'.The most critical region is the spar web region near to the root. The stress results obtained from the buckling analysis are shown in Fig.3.

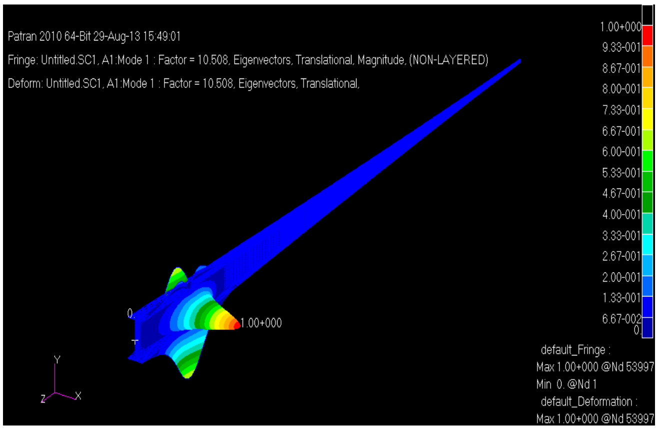

Fig.3 Eigen value stress plot

A thin sheet may buckle in a variety of modes depending upon its dimensions, the loading and the method of support. Usually, buckling loads are much lower than those likely to cause failure in the material of the plate. Therefore, plasticity factor need not be considered for those calculations. Crippling stress in such a case is given by,

$$\sigma_{cr} = \frac{\pi^2 k_c E}{12(1-\mu^2)} \frac{t}{b^2}$$

where:

K_c= Buckling coefficient which depends on edge boundary conditions and sheet aspect ratio (a/b).

E = Modulus of elasticity

μ = Elastic Poisson's ratio

b = Loaded edge.

t= Sheet thickness.

The critical region identified from buckling analysis is shown in Fig.4

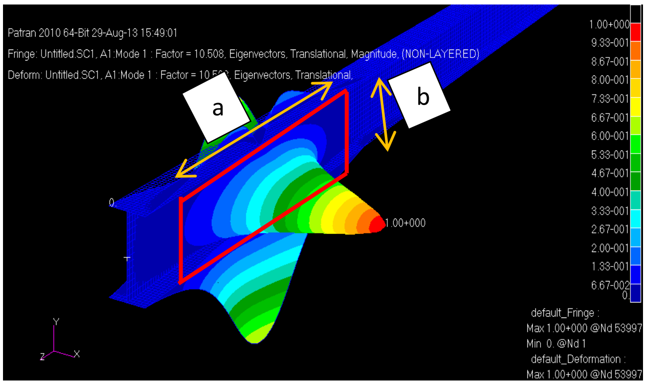

Fig.4 Critical region under buckling

From Fig.4, a=b=200 mm; Elemental stresses = 3245.0 N

$$\sigma_{cr} = \frac{\pi^2 k_c E}{12(1-\mu^2)} \frac{t}{b^2}$$

$$= \frac{\pi^2 * 4.0 * 71000}{12(1-0.33^2)} \frac{3}{200^2} = 58.93 N/mm^2$$

$$P_{cr} = \sigma * A = 58.93 * 600 = 353512 N$$

$$e = \frac{P_{cr}}{P_{app}} = 35351.2/3245.0 = \mathbf{10.89}$$

The theoretical buckling calculations are performed to validate the result from the FE analysis and Eigen factor is found to be '10.89', which is a closer value.

CONCLUDING REMARKS

[1] Eigen value buckling analysis points out that the spar is safe in buckling. It identifies an Eigen factor of '10.51'.

[2] Theoretical buckling calculations are performed to validate the result from the FE analysis and Eigen factor is found to be '10.89', which is a closer value.

[3] Static stress distribution throughout the spar web, from station 2 to station 7 is found to be lesser than 80 N/mm^2.Hence removal of more material is suggested in those locations after performing dynamic and fatigue analyses.

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