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Stress Analysis on Bulkhead Model for BWB Heavy Lifter Passenger Aircraft

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ABSTRACT

In modern aviation for passenger and military transportations, a new and efficient design in fuselage is necessary. BWB fuselage will confidently satisfy this requirement. BWB centerbody is the most load withstanding component among the full length of BWB fuselage structure. Unlike a conventional cylindrical pressurised Fuselage, the centre body of a BWB suffers from both internal cabin pressurisation and spanwise wing bending loads. The combined loading results in non-linear stress behaviour, whose complexity is undesirable for the design process. This project is fully concentrating on the stress analysis of rear structural pressure Bulkhead component used for the BWB centerbody configuration for passenger fuselage. A New combination of Multi-bubble and Box type Bulk head is proposed for the ultra heavy lifter by Boeing & NASA. In this project initially the Bulkhead is modeled for their given specifications and the stress analysis carried out in Ansys analysis software tool for the same configuration. Theoretical calculations for the bending stress and the values are validated with the numerically stimulated values. It is expected to prove that the BWB model with the multi bubble combined with Box type centerbody is more suited for the future ultra heavy lifter passenger aircrafts.

Keywords - *BWB, bulkhead, panel stress.*

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I. INTRODUCTION

It is generally known to provide a pressure bulkhead for enclosing, in a pressure tight manner, the tail end of the pressurized interior of an aircraft fuselage. The pressure bulkhead includes all structural components that are necessary for achieving an airtight and pressure-tight seal of the pressurized interior of the fuselage, and for taking up and further transmitting into the fuselage structure all of the forces that result from the pressure difference on the two opposite sides of the bulkhead. Generally, two types of bulkhead structures are known in the art. Pressure bulkheads of the first type are embodied as curved, stiffened membrane structures, for example in the form of a semi-spherical cup. Pressure bulkheads of the second type are embodied as a planar, skinned-over grid frame structures. The choice between these two types of pressure bulkheads is based on the respective prevailing boundary conditions, and especially, for example, the available space, the size of the cross-sectional area that is to be enclosed, and the like. Since the curved form of the first type of pressure bulkhead is advantageous for supporting, transferring and counteracting the arising forces, this type of pressure bulkhead can have a lighter weight and simpler construction. Namely, a membrane structure that is subjected to a pressure supports the resulting loads in directions along its curved surface only in the form of meridian forces and circumferential forces. The circumferential forces are all internal forces within the pressure bulkhead. On the other hand, the meridian forces must be taken up and supported by the surrounding structures of the aircraft fuselage around the edge of the membrane structure. Moreover, the meridian forces of the membrane structure have an outwardly directed force component around the edge of the membrane at the area of the transition or junction with the aircraft fuselage.

1.1 Theory involved in modeling

Unlike the traditional aircraft tubular fuselage, the high stress and weight problem associated with BWB pressurized cabin can be explained using the sketch in Figure 1. This figure illustrates a cylindrical and a square box fuselage under internal pressure p. In a cylindrical pressure vessel of radius R and skin thickness t, the pressure is resisted by uniform stretching resulting membrane stress is equal to p(R/t). In BWB box like fuselage, the nearly flat upper cabin wall resists the pressure by bending deformation. Let us model it as a simply supported beam or plate of length l, thickness t, then the maximum bending stress is equal to 0.75p(l/t)2. Assuming R is of same order as l, the bending stress is one order of magnitude higher. The problem is aggravated by the non-linear effect of compressive load acting on the deflected beam or plate. So in order to obtain an efficient structure, one must increase the bending stiffness using deep sandwich shell with light weight high-strength composite skin with Composite deep stiffener. The alternative is to use a multi-bubble concept with proper design; the adjacent bubble membrane stress resultant is balanced by tension in the intra-cabin wall.

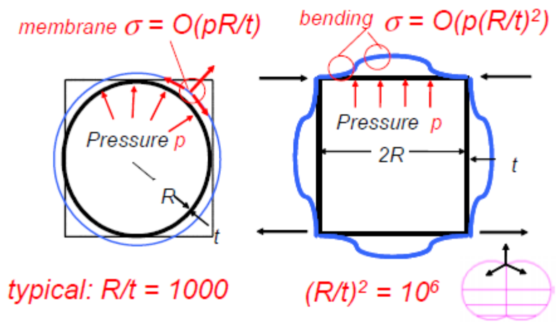


Fig.1 High bending stress associated with a non-cylindrical pressure vessel.

1.2 Simple plate theory for thin panels

In this area the Fig.2 shows the Plate with two edges free and 2 edges fixed:

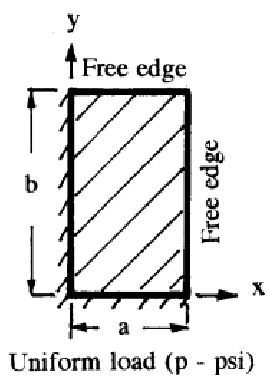


Fig 2. Plate with two edges free and 2 edges fixed

From plate theory the required maximum bending stress and shear force values for thee specified thin plate can be calculated as:

1. Max. Bending stress at x=0, y=b

$$f = -\beta_1 (p\frac{b^2}{t^2})(psi) \qquad \text{Eq. (1)}$$

2. Shear force at x= a and y= 0

$$V = k_1 pb(lbs/in) \qquad \text{Eq. (2)}$$

3. Bending stress at free edges, x=0 and y= b

$$f = -\beta_2 (p \frac{b^2}{t^2})(psi) \quad \text{Eq. (3)}$$

4. Max.shear force are free edges, x= 0, y= b

$$V = k_2 pb(lbs/in) \quad \text{Eq. (4)}$$

Where, co-efficient β_1, β_2, k_1, k_2 are taken from [2].

1.3 Ideal beam- column analysis

A simple nonlinear beam-column analysis may provide some initial sizing information. Consider a cabin roof segment, as shown in Fig. 1, where P is the axial load, q is the distributed running load due to normal cabin pressure, and EI is the beam bending stiffness over the span- length L. The critical bucking load Pcr for a simple-supported boundary condition is given by Pcr = π 2 EI/L2 . From beam-column theory (Ref.), the maximum deflection, bending moment, and bending stress at mid-span are given by equations (5) through (7).

$$w_{\max} = \frac{5q.L^4}{384EI} \frac{12(2\sec\mu - 2 - \mu^2)}{5\mu^4} \quad \text{Eq (5)}$$

$$M_{\max} = \frac{qL^2}{8} + \frac{5q.L^4}{384EI} \frac{12(2\sec\mu - 2 - \mu^2)}{5\mu^4} p \quad \text{Eq (6)}$$

$$\sigma_{\max} = M_{\max} \frac{y}{2I} + \frac{P}{A} \quad \text{Eq (7)}$$

Where,

$$\mu = \frac{\pi}{2}\sqrt{\frac{p}{p_{cr}}}$$

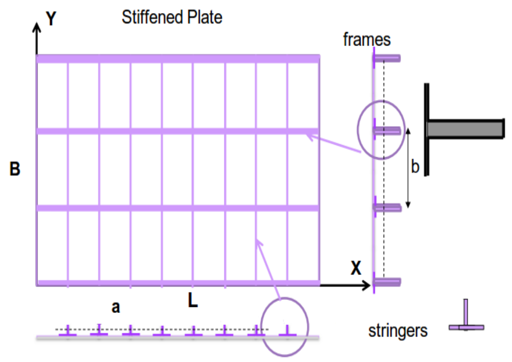
1.4 Stiffened plate analysis

Consider the biaxial stiffened plate shown in Fig. 2. The equivalent bending stiffness Dx, Dy along the x and y directions and the torsional stiffness H of a biaxially stiffend plate of thickness t can be approximately defined by equations (4) through (6). Let us assume that the plate-theory assumptions are applicable to a stiffened plate [1].

$$D_x = \frac{E_x t^3}{12(1-\nu_x \nu_y)} + \frac{E_x t Z_{0x}{}^2}{12(1-\nu_x \nu_y)} + \frac{E'_x I_x}{b} \quad \text{Eq (8)}$$

$$D_y = \frac{E_y t^3}{12(1-\nu_x \nu_y)} + \frac{E_y t Z_{oy}{}^2}{12(1-\nu_x \nu_y)} + \frac{E'_y I_y}{a} \quad \text{Eq (9)}$$

$$H = \frac{1}{2}(D_x \nu_y + D_y \nu_x + \frac{G_{xy} t^3}{3}) \quad \text{Eq (10)}$$



II. STRESS ANALYSIS

2.1 Analysis for case-1

Case-1 is having only 3 frame members and 2 stringer members as shown in fig below. The stringers are arranged along y- direction. Frames are formed along x- axis. Material property for the elements is constant for all of the members including plate with 5 mm thickness. Material is modeled with shell93 element.

Boundary conditions for x=0 & y= 0 lines are symmetry BC. For x=250, y=750 are having clamped edge BC. The uniform pressure load is given on the plate member.

Table: 1- Dimension specification: Units are in 'mm'

Item	Stringer(W1)	Frame(L1)
number of members	2	3
spacing	125	250
total length	250	750
height	15	20
thickness	2	2

The contours values correspond to σxx values for the face sheet bottom. Value is -56 MPa. The negative sign indicates compression. (See Fig.4), the values are shown in the x-component stress model fig.4 at the face sheet center; σxx varies from a tensile stress of 51 MPa at the top to a compressive stress of 56 MPa at the bottom. Following values for the bottom of the face sheet is for the y-component stress:

i. At the center, σyy= -28 MPa.

ii. At the clamped edge location (x=0, y=L1), σyy= 77 MPa.

The head-to-head comparison of the analytical values with the FEA values at the center of the structure is presented in the following table.2

Table: 2. Comparison at the center of the structure

Entity	Location	FEA	Theory
W		3.8mm	3.6mm
Σxx	Bottom	-56MPa	-50MPa
Σxx	Top	312MPa	350MPa
Σyy	Bottom	-28MPa	-20MPa
Σyy	Top	38MPa	105MPa

2.2 □for Stiffeners

σxx values at the top of the x-stiffener closest to the center & the following values at the top of this stiffener (see Fig.6):

i. At (x=0, y=L1/6), σxx= 312 MPa.
ii. At the clamped edge location (x=W1, y=L1/6), σxx= -653 MPa.

The head-to-head comparison of the edge stresses is given in the following table.3

Table: 3- comparison of the edge stresses

Entity	Location	FEA	Theory
Σxx	Bottom	116 MPa	100 MPa
Σxx	Top	-653 MPa	-704 MPa
Σyy	Bottom	77 MPa	78 MPa
Σyy	Top	-300 MPa	-403 MPa

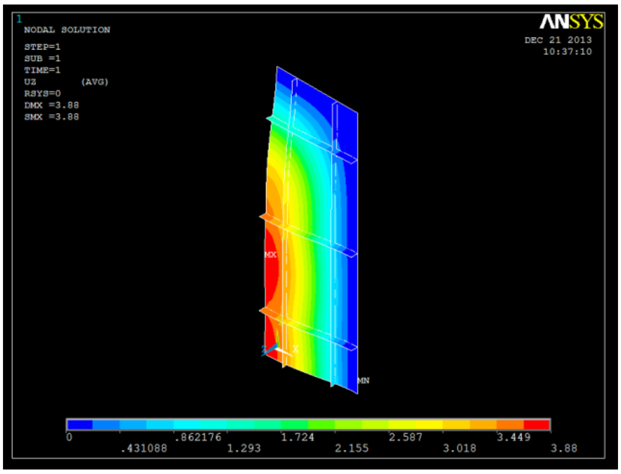


Fig.4 deformation of the structure

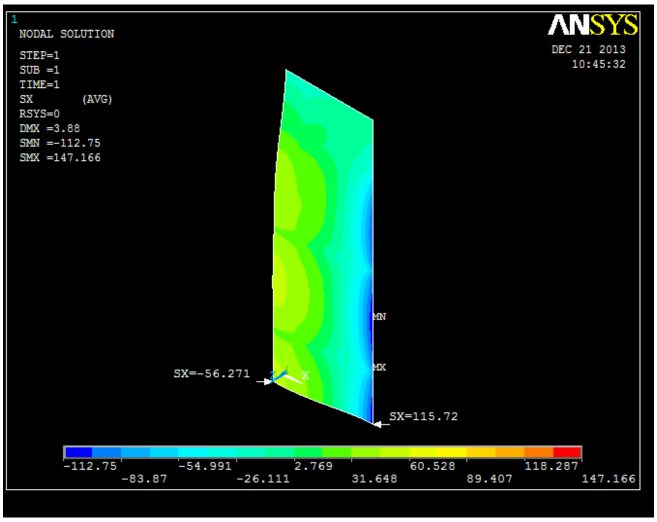


Fig.5 face sheet stress components

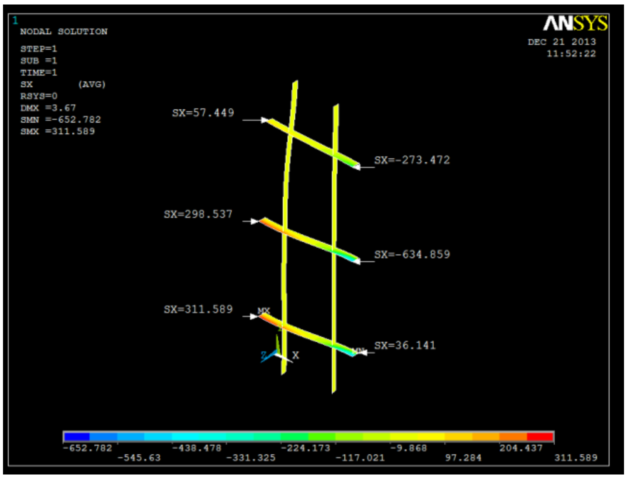


Fig.6 stiffener stress components

III. CONCLUSION

The deflection at the center is about 8% larger than the theoretical value due to shear deformation in the FEA model that is not accounted for in the analytical result. Correlation of stresses in the center is reasonably good. It might improve if solution for anisotropic plate were used. Also, the stiffeners are not at the centerline of the model, while maximum stresses in theory are calculated at the center. There is good correlation of the edge stress on the bottom of face sheet but the edge stress at the top of the stiffeners is overestimated by the theory. This is possibly due to the stiffeners not being at the centerline of the model while the maximum stresses in theory are calculated at the center. To get much stress concentration and stiffness for the given structural member, composite materials with high strength give possible static stability and good stiffness over higher internal pressure levels.

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