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Structural Design Optimization of An Aircraft Wing Stiffened Panel With Hat and I Section Stringer

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Abstract**:** ***Stiffened panel of aircraft consists of stringers which must be placed in proper spacing because increase in spacing decreases buckling strength and decrease in spacing increases weight. In order to find the proper optimum spacing structural optimization of aircraft wing stiffened panel is done to find the minimum weight satisfying all the design constraints and structural integrity to perform under operational loads. Aluminum / Composite materials are widely used in airframe structures because of its strength to weight ratio and stiffness to weight ratio when compared to conventional materials. Structural design optimization is carried out for stiffened panels of wing with HAT section stringer and I section stringer for different spacings from 75mm to 250mm for both metal and composite materials. A comparative study of design optimization is carried for both metal and composite stiffened plates. Thickness of skin is considered as design variables for all different sets of stringer spacings. Tsai-Wu failure criterion is used for satisfying strength and Eigen value approach is used for satisfying buckling criteria during optimization. The spacing at which the minimum weight is obtained satisfying all the structural design constraints is considered as optimum stringer spacing. Optimization deck for the above-mentioned strength and buckling criteria constraints is developed using design response level 1 cards (DRESP1) and solution-200 (SOL 200) for MSC Nastran solver to carry out the optimization.***

Key words**:** ***Composites; optimization; stiffened; stringers.***

I. INTRODUCTION

The wings are primary structure of an aircraft, which consists of spars, stringers, ribs and skin panels. The skin is very thin and less resistant to buckling when subjected to in-plane compressive loads and hence skin panels are break down by introducing the stringers to resist against buckling [2-4]. Panels can be stiffened by using stiffeners of different size and shape in transverse or longitudinal direction [5]. Aluminum/composites are used extensively in aerospace, automobile, and some of civil engineering structures because strength-to-weight ratio is higher in these materials [2,4]. Skin stiffened constructions are common in aircraft design because structural components in aircraft are subjected to compressive loads [3]. The objective of design optimization is to obtain the minimum structural weight of stiffened panel because aircraft structures are sensitive to weight. MSC Nastran is used as design optimizer, Tsai-Wu and Eigen value criteria are incorporated in an automatic way by exploiting the primary response constraint feature of design optimizer. The optimizer allows calculating the response quantities at every stage of design optimization using the primary response quantities like stress values and design variables values as inputs. To find an optimum feasible solution a structural design must satisfy all the response constraints given in input optimization algorithm. The structural design optimization is a gradient-based tool in which one must construct a mathematical idealization of a physical structural components and define appropriate structural responses in such a way that it provides an optimum sizing and minimum weight of stiffened panel of an aluminum/composite wings. A different component of stiffened panel is to be determined based on structural response constraints, subject to satisfaction of strength and buckling to find an optimum feasible solution. In the present study, uni-axial unit loads are considered for different set of stringer spacings of a stiffened panel for aluminum/composite materials. The stiffened model is considered as fused model for FE analysis and shown in fig.2.

II. OPTIMIZATION PROBLEM OF STIFFENED PLATES

The dimension of a stiffened plate is about 1400mm x 500mm and breadth of the plate is varied depending on the configuration of stringer spacings to fit the stringers to plate. The stringers are positioned parallel to loading direction. The cross section of stringers is HAT-section and I-section. The minimum thickness is considered for both metal and composite stiffened plates for initial values of design optimization. In composite stiffened plate, 8 ply symmetric balanced laminate plates with unidirectional fibres is considered. Tsai-Wu failure theory and Eigen value approach are used to satisfy strength and buckling failure criterions. The constraint for strength is satisfied if the value is equal to unity or less than unity and for buckling if the value is equal to or greater than unity.

Thickness of skin is considered as design variable, which can vary and stringer thickness of 2mm for aluminum and 2.72mm (each ply of 0.34mm thickness) for composite is kept constant.

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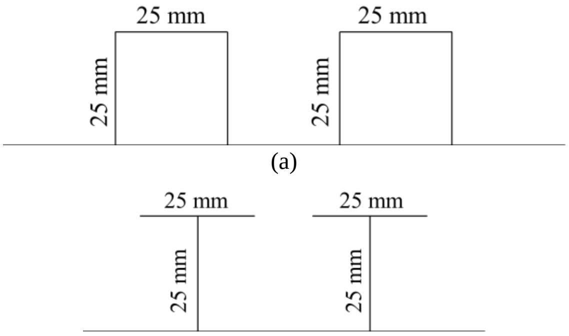
III. GEOMETRY OF STIFFENED PLATES

The stiffened panels are modelled with HAT-section and I-section stringers having different stringer spacings. Length of the plate is kept constant and breadth is varied depending on the configuration of stringer spacings to fit the stringers. The stringer spacing is varied from 75 to 250 mm with an increment of 25 mm. The initial thickness configuration is 2.72mm with four basic orientations of a symmetric balanced laminate for composite and 2mm for metal. The stiffeners are positioned along the length and parallel to the loading direction, the end panels are taken care of preventing from buckling to avoid any spurious results. The dimensions of a stiffened panel are chosen in such way that they represent aircraft fuselage/wing and similar structural panels. The dimensions of HAT-section and I-section stringers is shown in fig.1(a) and fig.1(b) and is kept constant for all the aluminum and composite models with different spacings. The material properties of aluminum are listed in Table 1 and the properties of carbon fibre composite (CFC) are listed in Table 2 and Table 2.1. The laminate stacking sequence is shown in Table 3.



(a)

(b)

Figure 1: (a) Dimensions of HAT stringer (b) Dimensions of I section stringer

Table 1: Material properties of Aluminum

Modulus of elasticity, E	Poisson's ratio	Density	Allowable stresses
7200 kg/mm^2	0.33	2.71×10^{-6} kg/mm^3	28.0 kg/mm^2

Table 2: Material properties of Composite CFC T-300

Modulus of elasticity (kg/mm^2)	Poisson's ratio	Density (kg/mm^3)
E1=12232.41 E2=815.4940	NU_{12}=0.32	1.5×10^{-6}

Table 2.1: Material properties of Composite CFC T-300

Longitudinal Allowable stresses (kg/mm^2)	Lateral Allowable stresses (kg/mm^2)	In-plane shear modulus (kg/mm^2)	Allowable stress for in-plane shear (kg/mm^2)
X_t =59.625 X_c=50.355	Y_t =3.375 Y_c =3.375	G_{12}=305.81	S=4.689

Table 3: Stacking sequence of composite (CFRP)

Component	Thickness (mm)	No. of Layers	Stacking sequence
Skin	1.36 / 3.0	8	[45/-45/0/90/90/0/-45/45]
Stiffener	2.72 / 3.0	8	[45/-45/0/90/90/0/-45/45]

IV. MODELLING AND METHODOLOGY

HyperMesh is used to develop FE models and design analysis is carried out using MSC Nastran. Post-processing is done using HyperMesh for the obtained results. The CQUAD4 elements are used for generating model. The mesh size is chosen in such way that it tends to converge. The design variables are defined using a DESVAR cards and design variable property relationship is developed using DVPREL1 cards. The primary response and design constraints are established along with design variable and property relationship in optimization analysis input deck.

V. LOADS AND BOUNDARY CONDITION

The uni-axial unit load per unit length is applied parallel to the stiffeners of stiffened plate as shown in figure 2. The loads are applied at finite element nodal points as a concentrated load, which is equivalent to unit loads. Direction of applied force and simply supported boundary conditions considered are represented in figure 2.1. Three degrees of freedom Fx, Fy and Fz (123) were held at the edges in the bottom plate and compressive loads were applied on the opposite edge. Fx and Fz (13) directions were constrained where the load is applied and Fz (3) direction was constrained on the remaining two sides.

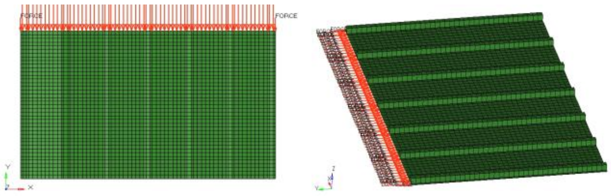


Figure 2: Finite Element Model and Loading condition

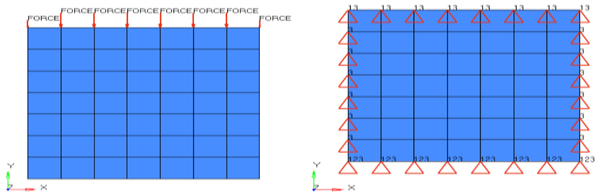


Figure 2.1: Loading direction and boundary conditions applied

VI. RESULTS AND DISCUSSIONS

The design optimization is carried out using MSC Nastran solver with strength and buckling constraints. The analysis is carried out considering a uni-axial compressive load and optimized thicknesses are checked for strength and buckling constraints, which are found satisfactory for optimized design weight. The design optimization for stiffened plates of different sets of stinger spacings from 75mm to 250mm has been carried out with an increment of 25mm spacing.

The design optimization results of HAT-section stringer showing optimized weight versus stringer spacings of Aluminum stiffened plates are displayed in fig.3 and results of Composite stiffened plates are displayed in fig.4 and values are tabulated in Table 3. The combined results are displayed in fig.5 and can be seen that for considered HAT-section models, least weight is found for a stiffened plate of 225mm stringer spacing and hence it is the optimum spacing for both Aluminum and Composite.

Similarly, design optimization results of I-section stringer showing optimized weight versus stringer spacings of Aluminum stiffened plates are displayed in fig.8 and results of Composite stiffened plates are displayed in fig.9 and values are tabulated in Table 4. The combined results are displayed in fig.10 and can be seen that for considered I-section models, least weight is found for a stiffened plate of 150mm stringer spacing and hence it is the optimum spacing for both aluminum and composite.

Table 3: Optimized weight values of HAT section Stringer stiffened panel

Stringer spacing (mm)	Weight (kg)	
	Aluminum	CFRP
75	4.3161	3.2454
100	3.8858	2.8366
125	3.4931	2.5432
150	3.1677	2.3659
175	3.3593	2.3607
200	3.2236	2.2771
225	3.1326	2.182
250	3.4959	2.4489

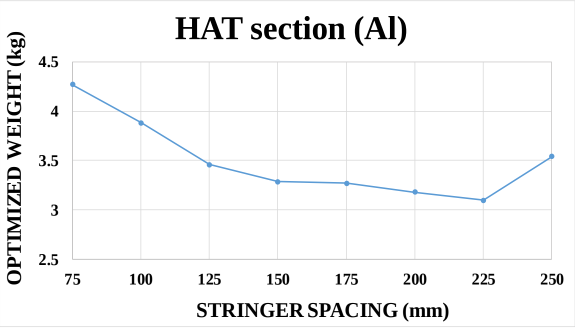


Figure 3: Optimized weight versus stringer spacing of Aluminum HAT-section stringer stiffened panel

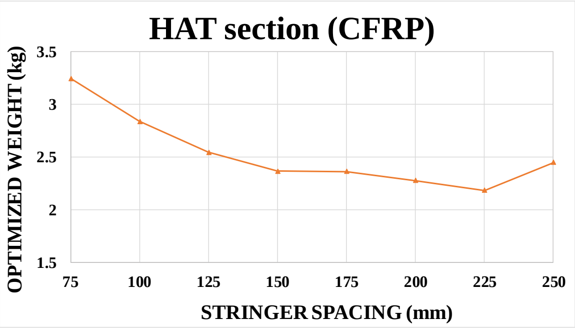


Figure 4: Optimized weight versus stringer spacing of CFRP HAT-section stringer stiffened panel

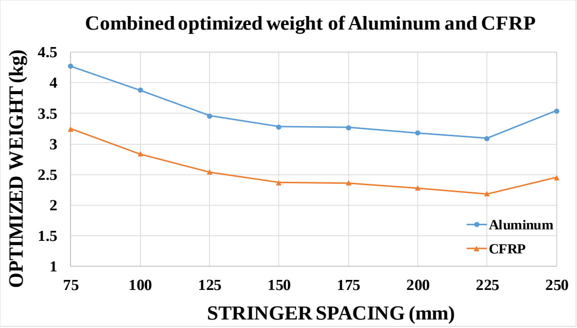


Figure 5: Optimized weight versus stringer spacing of combined Aluminum and CFRP HAT-section stringer stiffened panel

The buckling modes for 225mm stringer spacing HAT-section models of Aluminum and composite is displayed in fig.6 and fig.7.

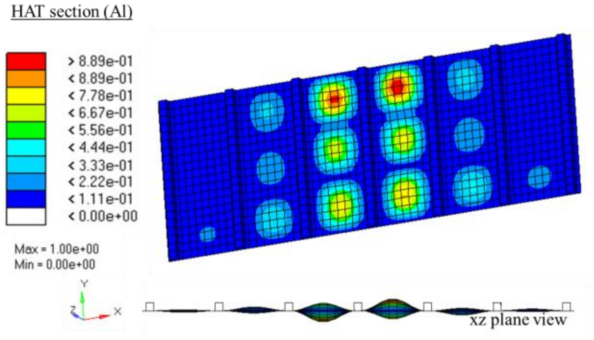


Figure 6: Buckling mode shapes for HAT-section stringer-Aluminum

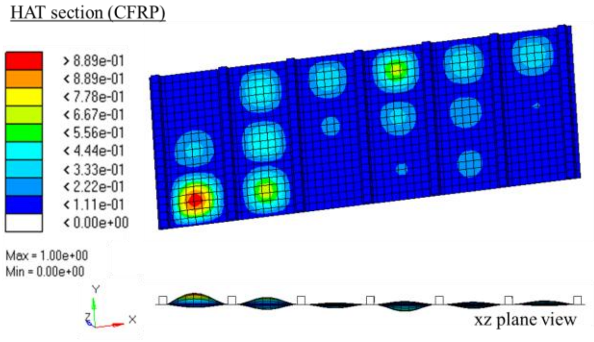


Figure 7: Buckling mode shapes for HAT-section stringer-CFRP

Table 4: Optimized weight values of I section stringer stiffened panel

Stringer spacing (mm)	Weight (kg)	
	Aluminum	CFRP
75	3.581	2.5935
100	3.2478	2.3249
125	3.0283	2.1916
150	2.9041	1.9882
175	3.0669	2.0641
200	3.1512	2.1372

225	3.0831	2.0794
250	3.6643	2.4538

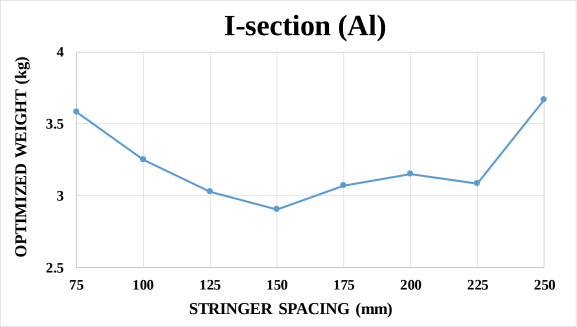


Figure 8: Optimized weight versus stringer spacing of Aluminum I-section stringer stiffened panel

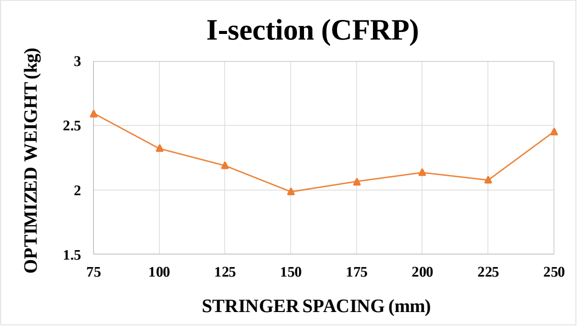


Figure 9: Optimized weight versus stringer spacing of CFRP I-section stringer stiffened panel

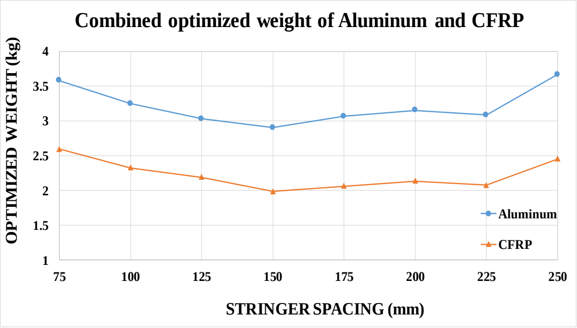


Figure 10: Optimized weight versus stringer spacing of combined Aluminum and CFRP I-section stringer stiffened panel

The buckling modes for 150mm stringer spacing I-section models of Aluminum and composite is displayed in fig.11 and fig.12.

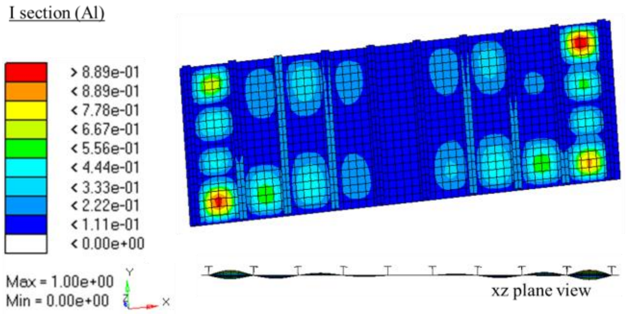


Figure 11: Buckling mode shapes for I-section stringer-Aluminum

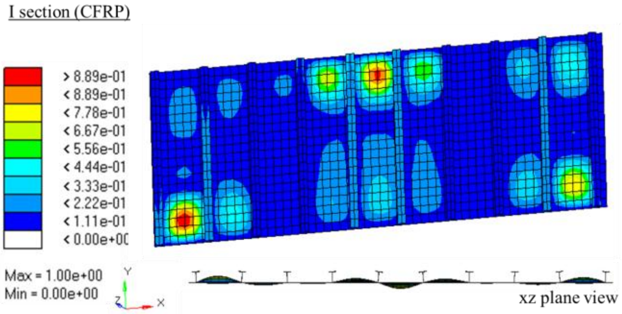


Figure 12: Buckling mode shapes for I-section stringer-CFRP

General observation is that, as the stringer spacing increases the weight of the panel decreases to certain point and with further increase in stringer spacing after that point weight increases. The combined results of HAT and I-section is displayed in fig.13 for Aluminum and combined results of HAT and I-section is displayed in fig.14 for CFRP.

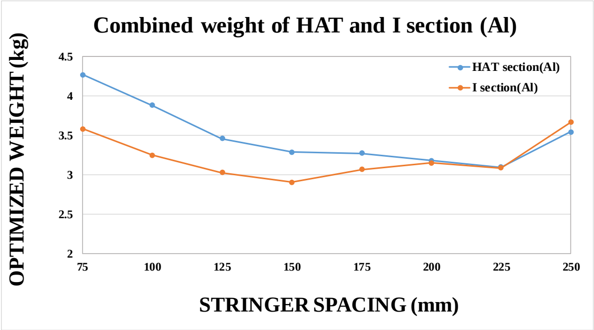


Figure 13: Combined graph of optimized weight versus stringer spacing for Hat and I-section stringer stiffened panel-Aluminum

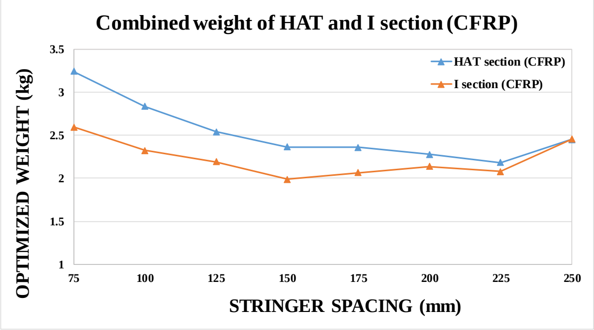


Figure 14: Combined graph of optimized weight versus stringer spacing for Hat and I-section stringer stiffened panel-CFRP

VII. CONCLUSION

Following conclusion can be drawn from the study:

1) It is observed that composite materials are better in both HAT and I-section stringer stiffened panels.

2) From the design analysis, it is found that 225mm stringer spacing is optimum for HAT-section stringer in both metal and composite stiffened plates considered and it is found that 150mm stringer spacing is optimum for I-section stringer in both metal and composite stiffened plates considered.

3) From the figures 13 and 14 it is found that I section is better than HAT section as the weight at optimum spacing is less in I Section stringer when compared to HAT section stringer stiffened panel in both metal and composite.

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