

REAR FUSELAGE STRUCTURAL OPTIMIZATION USING GENETIC ALGORITHM

ABDALMAGED ABDALLAH*[§] and MUTWAKIL SULIMAN ^{†¶}

*Aeronautical research and development center-Khartoum

[†]Karary University, Khartoum, 12304 Sudan

[§]maged20m90@gmail.com, [¶]mutwkil@hotmail.com

Abstract

Structural optimization is one of the most important tasks during the airplane structural design and yet there is a lack of well established procedures to determine the optimum design of aerospace structures. This paper represents development of structural optimization code based on genetic algorithm, and results for light aircraft aft fuselage optimal design using the optimization code. We have developed a MATLAB code according to the genetic algorithm and FE model for the composite light aircraft aft fuselage using MSC PATRAN to generate NASTRAN input file; the MATLAB code was coupled with MSC NASTRAN which used to perform linear static and buckling analysis. we obtained the minimum weight of the aft fuselage with a linear static and buckling constraints; the minimum weight is 21.6 kg; it has been obtained after 43 iterations; the margin of safety is of the optimum design is 1.22 and the buckling factor is 1.24 and hence the structure is free of static failure and buckling. The code is efficient in the conceptual and preliminary structural design phases to obtain the optimal aft fuselage weight.

Key words-*Optimization, Genetic algorithm, Multi-Disciplinary Optimization (MDO), buckling, Finite elements, MSC PATRAN, Composite materials*

I. INTRODUCTION

The aerospace manufacturing industry has shown increasing interest in the application of optimization methods for the optimum design of minimum-weight aircraft structural components [1]. An aircraft structural design requires a lot of work to find the best design that meet the strength and weight requirements so it needs a lot of iterations to find the structural member's dimensions that capable to carry varies loads without failure. To design an aircraft structure it is necessary to estimate the loads. Then, Here, the structure is ready to be designed and analyzed [2]. The structural sizing starts with determination of the allowable stresses, bending analysis to determine the dimensions of the longitudinal members sections; shear analysis to calculate the skin proper thickness, then buckling and crippling analysis, those steps seemed to be very complex and need a lot of design cycles because there are conflicts in the design objectives. So it's to use Multi-Disciplinary Optimization MDO approaches is useful to find the optimum design [3]. MDO Algorithms can treat a hundreds of design variables such as the dimensions of the structural members; composite materials orientation subjected to many kinds of constraints and converges to optimum solution quickly so that the design problem should be programmed in computer program to find the optimum design from a large field of varies designs [4]. One of the most effective algorithms used in the structural optimization is the genetic algorithm (GA). GA is a modern evolutionary optimization methods it is based on natural genetics; There are many advantages of using GA in the design over other optimization methods; GA deals with a population of variables which enhance the treatment of discrete design variables efficiently; also its uses the values of the objective function

and not the derivatives; and there is a mechanism to prevent the algorithm to get trapped in local optimum [5]. In GA optimization is done through many process and operators such as selection, crossover, mutation and elitism as shown in figure 2. The use of composite materials in aircraft structures has imposed many difficulties in the design and analysis because of the anisotropic nature of the materials [4]–[7]; so that the determination of the optimum design in the preliminary design is important process, it can reduce the time and cost in the later stages of the design [4], [5]. Recently aircraft design organizations develop their own software to design and optimize the aircraft structures, optimization software always based on finite elements (FE) analysis to check the design constraints because of the complexity of the shapes. In aircraft structural design the objective in most cases is to design an aircraft structure with minimum possible weight [5], but a lot of constraints subjected to the design objective such as allowable stress, allowable strain, and normal modes and buckling. Due to the complexity of the shapes of the structural components varies loads applied to the structure FEM software should be coupled with the optimization algorithms to avoid selection of unfeasible design.

II. FINITE ELEMENTS MODELING

The rear fuselage is built from 6 C-section frames with distance of 500 mm from each other, 10 Z stringers are distributed around the aft fuselage structure, and then the skin covered the frames and stringers; explain the structural layout of the aft fuselage; the structural layout has built in PATRAN .The structure was built from thin walled composite beams, frames and skin; 2D QUAD 4 shell elements type has been

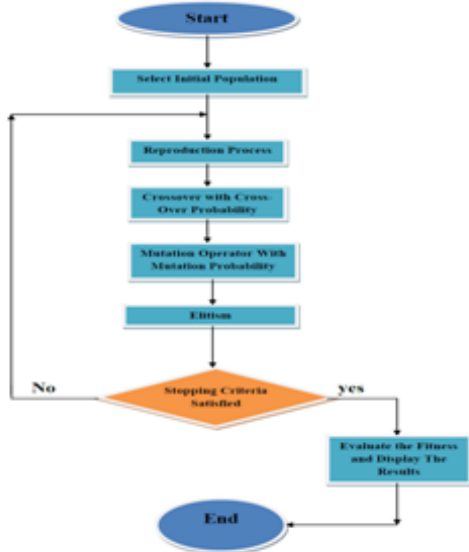


Fig. 1. genetic algorithm flow chart

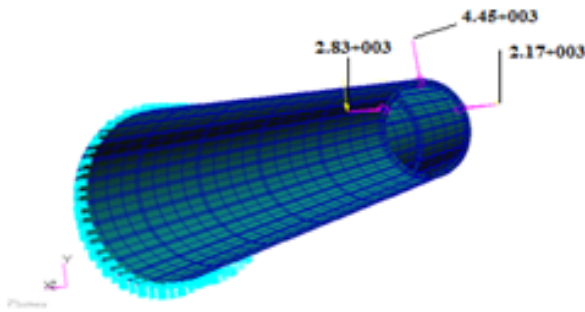


Fig. 2. Finite elements model.

Ply1	0
Ply2	45
Ply3	90
Ply4	-45
Ply5	0
Ply6	45
Ply7	90
Ply8	-45
Ply9	0
Ply10	45
Ply11	90
Ply12	-45

Fig. 3. Block representation of the ply thickness

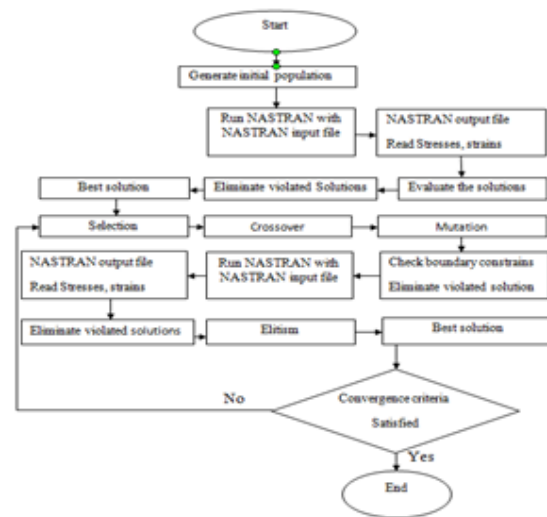


Fig. 4. structural optimization flow chart

used with the frames stringers and skin. The material used in the design is CFRP T300/N5208 with quasi isotropic layup the; mechanical properties are summarized in Table (III) The loads acting on the rear fuselage are tail load and total torque from fin these loads are inserted to PATRAN model and applied to nodes in the mean aerodynamic center of the horizontal tail and fin. The boundary conditions is the location of the fixation, if the rear fuselage is bonded to the forward fuselage, the fixation will be in the first frame flange surfaces; i.e. the first frame flange nodes will be given zero translation and rotations as shown in Figure (2).

III. STRUCTURAL OPTIMIZATION

The structure will be optimized using genetic algorithm, MATLAB which is connected to MSC NASTRAN. The MATLAB code changing the design variables in the NASTRAN input file in each generation then save the file in the then run NASTRAN after run ; the MATLAB code extract the stress strain and buckling factor; the MATLAB is working independently from NASTRAN this so that MATLAB need to pause about 13 seconds for the static analysis and 17 for the

TABLE I
MATERIALS PROPERTIES

Symbol	Values	Units
Longitudinal modulus E11	181000	[M Pa]
Transverse modulus E22	10300	[M Pa]
In-plane shear modulus G12	7170	[M Pa]
Major Poissons ratio 12	0.28	-
Longitudinal tensile strength X1t	1500	[M Pa]
Longitudinal compressive strength X1c	1500	[M Pa]
Transverse tensile strength Y2t	40	[M Pa]
Transverse compressive strength Y2c	246	[M Pa]
In-plane shear strength S	68	[M Pa]
Density	1.6E-6	[kg/mm3]
t Laminate thickness	0.1	[Mm]

TABLE II
REAR FUSELAGE LOADS

Loads	Values	Units
Horizontal tail load	-3022.2	[N]
Gravity	9810	[mm/sec2]
Vertical tail load	4450	[N]

TABLE III
LIMITS OF LAMINATES THICKNESSES

block no.	Thickness mm	Orientations [deg]
1	0.1-3	45
2	0.1-3	0
3	0.1-3	-45
4	0.1-3	90

TABLE IV
DESIGN VARIABLES

Symbol	Design variable
toprule t_{ff45}	Thickness of frame flange in orientation 45°
t_{ff0}	Thickness of frame flange in orientation 0°
t_{ff-45}	Thickness of frame flange in orientation -45°
t_{ff90}	Thickness of frame flange in orientation 90°
t_{f45}	Thickness of frames in orientation 45°
t_{f0}	Thickness of frames in orientation 0°
t_{f-45}	Thickness of frames in orientation -45°
t_{f90}	Thickness of frames in orientation 90°
t_{st45}	Thickness of stringers in orientation 45°
t_{st0}	Thickness of stringers in orientation 0°
t_{st-45}	Thickness of stringers in orientation -45°
t_{st90}	Thickness of stringers in orientation 90°
t_{sk45}	Thickness of skin in orientation 45°
t_{sk0}	Thickness of skin flange in orientation 0°
t_{sk90}	Thickness of skin flange in orientation -45°

buckling this increase the solution time; to reduce the solution time it is necessary to solve specific number of chromosomes each generation, in our code we forced the MATLAB code to analyze the chromosomes that have best fitness than the best fitness in the last generation. The following sections illustrate details of selection of the design variables, objective function, and constraints.

A. Design Variables

The design variables are the ply thickness of frames, frame flanges, stringers, and skin at $45/0/-45/90$ orientations and hence the design variables are 16, they representing the thickness of ply in 4 orientations for the different structural members, Table (III) summarizes the design variables (structural members thicknesses).

design variables will be changed discretely i.e. the ply at any orientation in terms of weight minimizing is just removed and no change the thickness so block representation [7] can be applied Figure (3). The Failure criteria used in the optimization code in the mathematical model in equations (1-3) is TSI-WU.

TABLE V
OPTIMIZATION RESULTS

toprule Members/orientations	45	0	-45	90
toprule Frame flange	1.3	0.1	1.3	2.5
Frame web	0.7	1.7	0.5	0.7
stringers	1.5	0.3	0.5	0.1
skin	0.1	0.1	0.1	0.4
toprule				

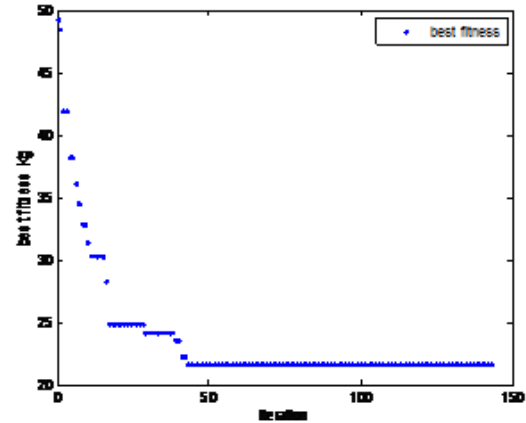


Fig. 5. Best fitness history

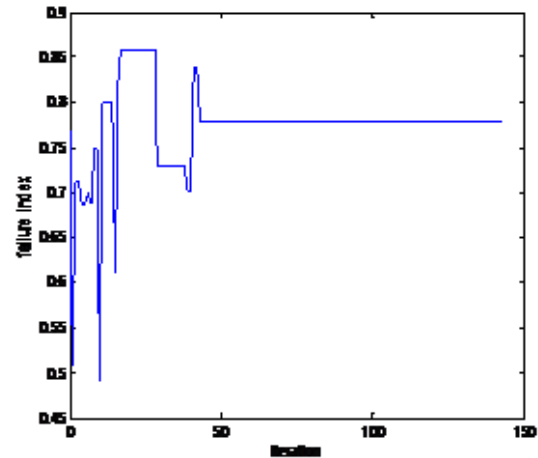


Fig. 6. Failure index history

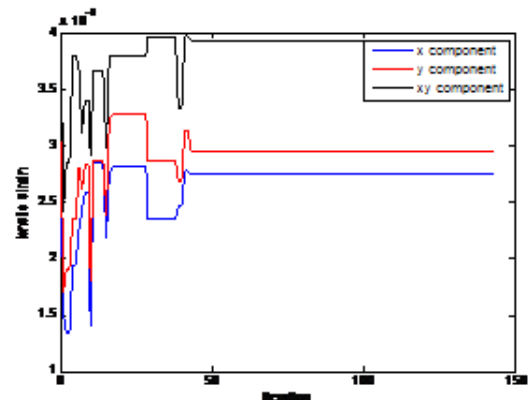


Fig. 7. Tensile strain history

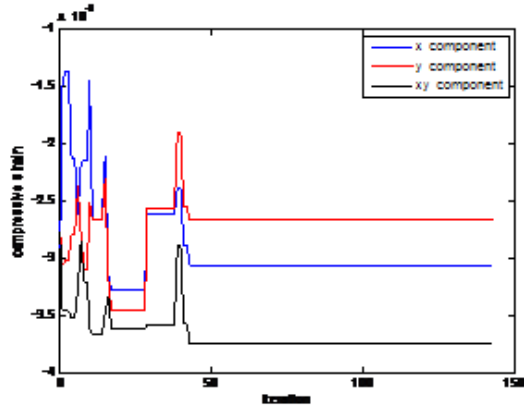


Fig. 8. Compressive strain history

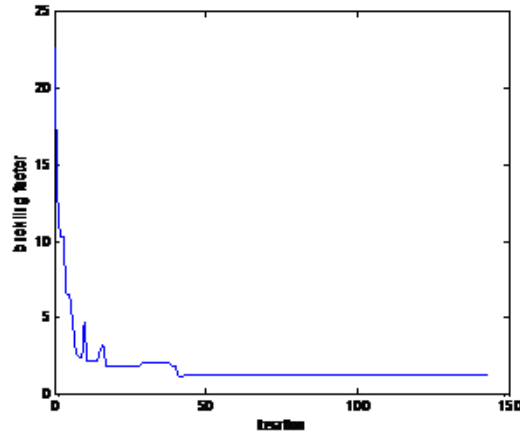


Fig. 9. Buckling factor history

B. Objective Function and Constraints

The optimization problem can be written in the following form:

Min m (Minimum mass) , Subjected to:

$$F.I < 1 \quad (1)$$

$$-0.004 \leq \epsilon \leq 0.004 \quad (2)$$

$$\lambda > 1 \quad (3)$$

Where $F.I$ is the failure index, ϵ is the strain and λ is the buckling factor. The limits of laminates thicknesses are shown in table (IV).

C. The Optimization Algorithm

The Structural optimization code as shown in figure (4) can be represented by the following algorithm.

D. Optimization Parameters:

The following parameters we used with optimization code:

- 1) Maximum iterations number =800
- 2) Population size =700
- 3) Selection method: roulette wheel

- 4) Crossover: single point crossover with crossover probability of 0.95
- 5) Mutation: flip mutation with mutation probability of 0.01
- 6) Tolerance =0.1mm
- 7) Termination criteria: when achieve 100 equal solutions.

IV. RESULTS:

Running the optimization code the following results in table(V); has been obtained. The results represent the minimum thicknesses required to optimize the structural components of the composite aft fuselage.

The numerical values in Table (V) are the structural members thicknesses that optimizes the structural weight of the rear fuselage; the corresponding objective function value is 21.6 kg, the above design satisfies the stress, strain and buckling constraints. Figure (5) shows the history of the objective function; as shown in Figure (6) that the optimization code is terminated after 143 generations. Figures (6-9) shows the history and the corresponding results for failure index, tensile strain, compressive strain and buckling factor respectively. The optimization code reached the optimum design after 43 iterations (Figure 5) the minimum weight is 21.6 . Figure 6 shows the failure index according to the TSI-WU failure criteria according to the graph the failure index is 0.79 this means the structure is safe with a margin of safety of 1.22 . The compressive and tensile strains (Figure 7, Figure 8) are within the limitations in equation 2 this means the optimum design is free from excessive deformation. The buckling factor history (Figure 9) indicated that all the selected solutions in each iteration is free from buckling and the buckling factor of the best solution is above 1.

V. CONCLUSION

In this research a computer code based on genetic algorithm has been developed to determine the optimum structural design for a composite rear fuselage of a light aircraft; the objective function is the minimum mass of the aft fuselage subjected to static and buckling constraints; the optimization code was developed using MATLAB and the code has coupled with MSC NASTRAN SOL101 and MSC NASTRAN SOL105.FE model for light aircraft aft fuselage has been created in MSC PATRAN and NASTRAN input file has been generated , those files updated by MATLAB each iteration to determine optimum combination of the design variables, we achieved the optimum design after 43 iterations. For the improvement of performance of the optimization code it will be useful to add the penalty function instead of the death penalty used in this code to treat the violated solutions.

REFERENCES

- [1] Odeh Dababneh, Timoleon Kipouros, James F. Whidborne, Application of an Efficient Gradient-Based Optimization Strategy for Aircraft Wing Structures journal of aerospace, MDPI January 2018. www.mdpi.com/journal/aerospace
- [2] Denis Howe, Aircraft loading and structural layout, professional, Engineering Publishing Limited, London and Bury St Edmunds, UK; 2004.
- [3] T.H.G. Megson, Aircraft structure for engineering students, 4th edition, Elsevier aerospace series, 2007

- [4] Marwan Maurizio Chedid, Optimization of Composite Materials using a Multilevel Decomposition Approach, MSc Research, Cranfield University, 2009.
- [5] Singiresu S Rao, Engineering optimization theory and practice, 4th edition, Wiley, New York, 2009.
- [6] Christos Kassapoglou, Design and analysis of composite structures with applications to aerospace structure, 2nd edition, Wiley, New York, 2013.
- [7] Rongxin Xu, Optimal Design of a Composite Wing Structure for a Flying-Wing Aircraft Subject to Multi-constraint, MSc Research, Cranfield University 2012.
- [8] Michel van Tooren and Lars Krakters, Multi-disciplinary Design of Aircraft Fuselage Structures International Journal of Mechanical, aerospace, Industrial, Mechatronic and Manufacturing Engineering Vol:7, No:5, 2013
- [9] MSC Patran Laminate Modeler Users Guide; MSC Software Corporation: Santa Ana, CA, USA, 2008.