Multistage topology optimization for attaining light weight emergency cot with enhanced spinal immobilization capability

Musaddiq Al ALi	Muazez Al ALi	Amjad Sahib
Mr.	Dr.	Mr.
Hiroshima University	University of Baghdad	University of Wasit
Higashihiroshima, Japan	Baghdad, Iraq	Wasit, Iraq

ABSTRACT

Spinal Injuries are common for traffic ascendants. Securing spinal position and eliminate unnecessary moving is vital during emergency transport. The purpose of this paper is to introduce enhance the design for a cot that handles spinal position securely, and with lowest cot weight as possible. This will be done by design and optimization composite based cot. The main objective is secure displacement of the Cot due to the static load, i.e. patient weight, and dynamically induced displacement due to transportation vibration. The system consists of two parts, first, a mobile cot to transfer the patient to and from the ambulance helicopter, and the second part is the shelf like support. to maximize strength to weight ratio with minimizing cost, hybrid composite materials (carbon fiber -epoxy and glass fiber -epoxy) are used for the mobile cot. Genetic algorithm gave preliminary design, i.e. the stacking sequence and ply angle. Displacement is less than 2 mm. Shape optimization extremum thickness of ply for shifting the range of natural modes from working vibration range. Topology optimization is used to designed stiffener. The processes shifted the natural mode with 35%. To secure the patient. The polymeric cellular pillow is designed using inverse homogenization. Aluminum is used as the material design for fixed bed. The supporting parts designed using two topology optimizations strategy (conformal lattice structure CLS, and free topology optimization) targeting von mises stress minimization. free topology optimization shows better results 38% compared to CLS topology optimization. The main bed structure is stiffened with topology optimization based stiffener design. It showed 59% improvement in vibrational characteristics.

NOTATION

C compliance (Pa^{-1})

d the distance of neighbor elements to the central one

E modulus of elasticity (Pa)

F force (N)

K finite element Stiffness matrix (N/m)

mf mass fraction

N number of elements

r checkboard filter radius

S stiffness matrix (Pa)

t linkage criterion

u element displacement (m)

V domain volume (m^3)

V_d volume fraction

W plate lateral displacement (m)

x element density

Y local coordinates

ε strain field

σ stress field (Pa)

ω frequency (Hz)

λ adjoint operator

Γ Global domain

Ψ objective function

Ω local domain

INTRODUCTION

Spinal injuries are common for automotive accidents and falling incidents. In certain cases, such as remote areas. patient transportations can be only done by using helicopter ambulance. As an aerial vehicle, optimum weight handling is a vital issue. In order to improve weight capacity, the need for designing light emergency cot is needed. In other hands, spinal injuries have certain specifications to be met, otherwise, it will be fatal for the patient. First, spin should be secured both statically and dynamically. i.e., body inertia reaction with acceleration should be eliminated. Cot lateral and normal displacement should be limited as much as possible. In the case of dynamic and vibrational induced motion, a cot should withstand deformation, and the occurrence of cot natural frequencies should be shifted beyond working vibration spectrum. Secondary considerations should also be taken into consideration, such as handling in and out of the ambulance space, and optimal space handling of possible attached specialized emergency equipment. The design is the activity in which engineers accomplish the preceding task. The designer task is to create set of specification for making or manufacturing. Optimization is a technique for improving or increasing the value of some numerical quantity that improves or satisfy certain conditions. The current work is an attempt to introduce design using shape, and topology optimization associated with a genetic algorithm, as multistage design for a specialized cot to meet spinal injury requirements. Targeted materials are hybrid fiber composites (carbon fiber-epoxy, and glass fiber -epoxy), ABS polymer, and Aluminum. Fiber-reinforced composite materials are continuing to replace the conventional metals in primary and secondary aerospace structural elements owing to their good mechanical properties to weight ratio. Material selection is based on the availability, ease of manufacturability, and light weight. Getting optimal design is being studied intensively since last century. To achieve feasible mechanical design for the certain application, practically there are several conflicting aspects to be considered. For example, global minimum compliance of a design domain is not associated with minimum stress field distribution. To locate a solution for which, the design variables and constraint, satisfy the design criterion in the best way of minimum triage of all needed or desired aspects; multi objective optimization gives such opportunity. Heuristic and meta heuristic methods were intensively used. Metaheuristic methods, such as genetic algorithm (GA) and particle swarm optimization try to mimic biological activities. They prove their competitiveness with another optimality criterion. Yet, they lose their edge with increasing design variables. The direct use of GA (Ref. 1) is questionable for topology optimization such that, practically, topography to be optimized are complicated in nature, making finding a valid design with the orthodox method a challenging task. Multi-objective optimization (Ref. 2) in general form can be GA optimization target. The genetic algorithm has been used in design composite structures. Riche and Haftka studied stacking sequence optimization of the thin composite plate (Ref. 3). Liu et al studied stacking sequences of predetermining fiber orientations for maximizing buckling load (Ref. 4). Park et al, used Finite element analysis as a numerical solution to address stacking sequence and orientation considering moderate thick plates (considering first order shear deformation theory), optimizing the plate using a genetic algorithm (Ref. 5). Farshi and Herasati implemented Tsai-Hill criterion, to develop optimality criterion based optimization technique for layer thickness and orientation (Ref. 6). Topology optimization has been developed rapidly in last decades, and still a considerable attractive topic to be addressed due to free computer design. It based on based auto design in order to find the optimal shape of the designed part based on objective subjected to the constraint. Topology optimization (TO) be designed method based on a mathematical scheme to introduce non-existence material within design space to get designer properties such as light weight or certain mechanical properties. Topology optimization was been developed from Maxwell dilemma of optimal weight truss design, by Michell (Ref. 7). Himp (Ref. 8) (1) studied strain field by adopting slip line, which at that time was regarded as an important aspect of plastic deformation implementations. Drucker et al (Ref. 9) applied constant dissipation per unit volume as their study to stress strain fields and strain energy. Chan (Ref. 10) study the optimization of static stability of truss structure by developing a technique to determine topographic based strain filed. Charrett and Rozvany (Ref. 11) adopted Prager – shield implementation in order to find optimal design criterion considering rigid-perfectly plastic systems under multiple loading. Rozvany and Prager (Ref.12) studied optimal design of grillage like continua. Their approach was spatial distribution within confined grillage units. Rossow and Taylor (Ref.13) used finite element method as a numerical solution to find the optimum thickness of variable thickness sheets. Potential energy for the elastic sheet in plane stress assumption was addressed. By introducing holes into plate structure, this work founded shape optimization. Cheng and Olhoff (Ref.14) implement finite element method as a numerical solution to optimize the thickness of annual plate with stiffened like approach. Bendsoe (Ref.15) studied Solid Isotropic Material with Penalization (SIMP) based on Taylors work.

GENETIC ALGORITHM OPTIMIZATION

Optimization is a field of applied mathematics consisting of a collection of principles and methods used for the solution of quantitative problems in many disciplines, including physics, biology, engineering, economics, and business, evolutionary methods, and control. The methods that used in this research are divided into two main types, first, approximation methods, and that achieved by using linear programming with random equations sets, and the

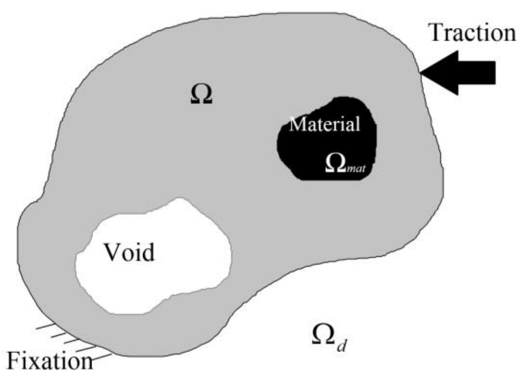
Presented at the 6th Asian/Austrailian Rotorcraft Forum / Heli Japan 2017, Kanazawa, Japan, November 7-9, 2017.

second type represents in Knowledge-based information systems or Evolutionary computing algorithms are designed to mimic the performance of biological systems, and that the Genetic Algorithms. the genetic algorithm (GA) use techniques derived from biology and rely on the application of Darwin's principle of survival of the fittest. When a population of biological creatures is allowed to evolve generations, individual characteristics that are useful for survival tend to be passed on to future generations, because individuals carrying them get more chances to breed. In biological populations, these characteristics are stored in what called Chromosomal Strings. The mechanics of natural genetics is based on operations that result in the structured yet randomized exchange of genetic information between the chromosomal strings of the reproduction parents and consists of Reproduction, Crossover, occasional Mutation and Inversion of the chromosomal strings.

SOLID ISOTROPIC MATERIAL WITH PENALIZATION

Solid Isotropic Material with Penalization (SIMP) is a scheme apply for discretized design domain to find smooth optimal structure.in which, material properties set to be constant for the discretized domain, however, the existence of building block which is set in what so-called density function composed of material existence ρ of conditioned power multiply by mechanical properties.

Figure 1. Topology optimization Problem



$$\lim_{volf.\to 0} x\{\Gamma(\Omega\cap\Omega_{mat}=0\ \ )\}$$

$$Extermum.,\ \Psi(\rho)\,|E_{\min\to 0}+x^{q}(E_{\min\to 0}+E_{mat\to 1}) \quad \ldots 1$$

$$s.t.\quad \int_{\Omega_d}\rho dx\le V_d\ ,\ 0<x_{\min}<x_e<1\quad \forall x\in\Omega_d$$

Where $\Psi(\rho)$ is objective function,

Power (q)that satisfy condition of two dimensions (Ref.16) set to be within

$$q\in\left]15\frac{1-v}{7-5v},\frac{3-3v}{2+4v}\right] \quad \cdots.\ 2$$

The solution in the scope of current scheme face some challenges as checkerboards and Nonexistence. The latter is Mesh dependency problem so Nonexistence tends to introduce non-existence element, severely, to satisfy solution with decreasing value of objective function. To solve it, relaxation principal is introduced, modifying density function with what so-called gray region (Ref.17) (0 < ρ <1). As well as gray area, heuristic searching with sufficient constraint will be a remedy. Checkerboards is also a byproduct of discretization. The solution in it tends to be non-applicable due to mesh dependency. One of an effective solution uses high order elements, however, computation resources and time will easily be consumed under pressure of real life complexity of design domain. Another solution is filtered independence filtering process. One of which, Sigmund (Ref.18) was introduced

$$\frac{\partial f'(\rho)}{\partial x_e}=\frac{1}{x_e\sum_{n=1}^{N}(r_{\min}-d(e,n))}\sum_{n=1}^{N}(r_{\min}-d(e,r))x_n\frac{\partial f(\rho)}{\partial x_e} \quad \cdots 3$$

Where $d_{(e,n)}$ is distance between central element x_e and each neighbor elements $x_{(n=1\to N)}$. The produced modified sensitivity will update the designated Optimally criteria.

HOMOGENIZATION

Homogenization is a mathematical technique used intensively in the last decades to calculate accurate effective properties of a composite structure. The Early shade of such capability might be found in Hill (Ref.19). In his work, he adopted energy approach. Sanchez et al (Ref.20) followed by Bensoussan et al (Ref.21), successfully established the applicable fundamentals to use homogenization for composite materials. Within topology optimization topic, Bendson and Kikuch (Ref.22) studied successfully the use of homogenization method as topology optimization scheme. Finite element method played a vital role in such development. The homogenization method is based on study local unit cell such as Here the use of periodic base cells (PBCs) to be generalized to the structure (Ref. 23, and 24). Such generalization force to adopt periodic boundary condition to ease the calculation of field within the structure. The microscopic effective tensor of properties can be presented periodically as(Ref.25)

$$E^{H}_{ijkl}=\frac{1}{|V|}\int E_{pqrs}(\varepsilon^{0(ij)}_{pq}-\varepsilon^{ij}_{pq})(\varepsilon^{0(kl)}_{rs}-\varepsilon^{kl}_{rs})dV \quad \ldots 4$$

Here, V is unit cell volume. E_{pqrs} , is the cell property tensor. $\varepsilon^{0(ij)}_{pq}$, is the external known field to be applied. ε^{ij}_{pq} , is the varying associated field of finding. Representative Volumetric Element (RVE), is increasingly used, associated with homogenization to calculate effective mechanical properties of composites (Ref. 26). RVE is the minimum unit cell in which static fields are sufficiently representative. The word “sufficient” means mathematically

$$\sum_{e=1}^{N} \frac{\left(\sigma^* - \langle\sigma\rangle\right)^2}{\langle\sigma\rangle} \quad \ldots 5$$

Which is the Chi square (χ^2) test. Volumetric unit calculations can be ease according to a specific application such as for fiber reinforced composites.

Here σ^*, and $\langle\sigma\rangle$ are the normalized average value of the stress in the current unit cell and an average of it respectively. The topology optimization of the microstructure can be performed in terms of minimization of potential energy.

$$Extermum \sum_{ij=1}^{2} r_{ij} (\overline{E}_{ijkl}^{H}) \mid E_{ijkl}^{H} = \frac{1}{|Y|} \sum_{e=1}^{N} (u_e^{ij})^T K_e u_e^{kl}$$

$$Y =]0, Y_1^o[\times]0, Y_2^o[\times]0, Y_3^0[, \quad ..6$$

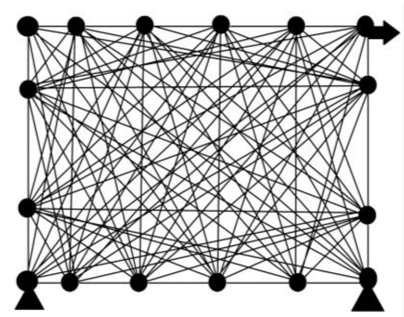
$$s.t. \int_{\Omega} \rho^e d\Omega = V_d .$$

Here, r_{ij} denotes to waiting for a factor to balance the objective function. $\overline{E}_{ijkl}^{H}$, is the effective properties formulation according to bounding formulas such as Wiener bounds, and Hashin-Strikman bonds (Ref. 27-29).

CONFORMAL LATTICE STRUCTURES OPTIMIZATION

Additive manufacturing of polymeric based materials gives theoretically, thermal stress-free structures, with good surface finish. this will ease manufacturing process and extra-design consideration for overcoming such problems, especially with complicated shapes such as inverse homogenization material design. However, here is an impressive advance in metallic additive manufacturing; still, surface finish within complicated lattice is challenging. Truss like structure can be a solution. The capability to cleaning the structure will increase the expected fatigue life. Truss like lattice structure can be formulated with using ground structure method. It states that the structure can be optimally built by adding or vanishing chosen links linking between an appropriate fixed set of nodal points. Such as in Conformal Lattice Structures (CLS) (Ref. 30).

Figure 2. conformal lattice structure problem scheme



The basic optimization scheme is

$$\max_{t>0} \ \min_{u}, \frac{1}{2} u^T (\sum_{e=1}^{N} t_e K_e) u \quad \ldots 7$$

$$s.t. \quad \sum_{i=1}^{m} t_i = V$$

SENSITIVITY ANALYSIS

Topology optimization in terms of sensitivity analysis approaches needs derivative to apply an iterative Lagrangian multiplier. As Heuristic and meta-heuristic methods are used to extremum functions for the field of optimization, heuristic methods, as Lagrangian is implemented in many topology optimization types of research, showing its effectiveness and simplicity to apply and control. Adding to that, metaheuristics showed in some techniques weakness toward increasing design variables number. Some research's value advancing of quantum advancing in quantum-based searching approaches and advancing in metaheuristic hyperdilation, but in the scope of near future, heuristic searching proved to be as a keystone in global optimization of many variables as topology optimization. Global search algorithms need sensitivity analysis. In such case, derivative might contain certain difficulties, especially, the derivative should be in term of design variables. First order sensitivity analysis is required be perform each iteration. The adjoint variable method is used to develop a unified formulation for representing response variation in term of variation design. Aggregation objective function which subjected to a constraint with respect to design variable x. finite element based sensitivity analysis using adjoint method gives

$$\frac{d\Psi}{dx_e} = \lambda^T (\frac{dF}{dx_e} - \frac{dK}{dx_e}) + \frac{\partial\Psi}{\partial x_e} \quad \ldots 8$$

Here, Ψ is a density related function to be derivative.

DESIGN PROCESS

The design process is divided into three major steps. Steps are categorized according to part to be designed. The first step is designing the light weight bed, which should be mobile to carry the patient from and to the aerial ambulance. The second step is designing the fixture metallic base, the third step is designing auxiliary parts such as the securing techniques for patient and cot itself and evaluate the completed parts.

1- Step 1 Designing the light weight bed (Composite structure)

Uni-directional carbon fiber – epoxy system will be the main body of cot that directly withstands the patient weight. It should be satisfying the following purposes: its normal displacement should as minimum as possible, add to that, the natural frequency should be controlled to avoid undesired noise during unloading transportation and to avoid interlaminar failure due to the harmonic motion. In general, the design is being considered as a thin plate, subjected to a normal load. Preliminary design of static worst-case scenario is being adopted to design ply orientations. Worst case scenario was chosen to be point load on the simply supported plate.

$$\min.\ W_{mn} \mid S^{-1}F \qquad s.t.\ \ \theta \in [0,180] \qquad \ldots 9$$

Where W_{mn} is normal displacement of the plate which comes from the following?

$$\begin{bmatrix} \hat{S}_{11} & \hat{S}_{12} & 0 & \hat{S}_{14} & \hat{S}_{15} \\ \hat{S}_{12} & \hat{S}_{22} & 0 & \hat{S}_{24} & \hat{S}_{25} \\ 0 & 0 & \hat{S}_{33} & \hat{S}_{34} & \hat{S}_{35} \\ \hat{S}_{14} & \hat{S}_{24} & \hat{S}_{34} & \hat{S}_{44} & \hat{S}_{45} \\ \hat{S}_{15} & \hat{S}_{25} & \hat{S}_{35} & \hat{S}_{45} & \hat{S}_{55} \end{bmatrix} \begin{bmatrix} U_{mn} \\ V_{mn} \\ W_{mn} \\ X_{mn} \\ Y_{mn} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ Q_{mn} \\ 0 \\ 0 \end{bmatrix} \qquad \ldots 10$$

Real coding GA is used to identify ply angles. An analytical solution is being adopted, using Navier's solution. Topology optimization is used for the plate that results from GA step in order to optimize ply thickness for maximizing natural frequency, and minimizing plate displacement, with decreasing weight as much as possible. as a multi objective optimization problem, it is computational power consumer, add to the that the difficulties of optimality criterion. For the case of weight and frequency, the required range can be determined, so minimizing displacement with setting bounds for the other desired characteristics is suffice. Optimization scheme can be summarized in eq

$$find \quad x \rightarrow x^{q} \mid q = 3$$

$$\min.\ ,\ W_{mn} \ \mid E_{mat\rightarrow 1} + x^{p}(E_{\min\rightarrow 0} + E_{mat\rightarrow 1})$$

$$s.t. \begin{cases} \int_{\Omega_d} \rho dx \leq mf_d \ ,\ 0 < x_{\min} < x_e < 1 \qquad \forall x \in \Omega_d \\ \omega. \in]\omega^{u}, \omega^{l}\ ] \end{cases} \qquad \ldots 11$$

to ensure the structural rigidity of the plate, stiffeners are used. The optimal location of stiffeners and stiffener topography itself can be deduced using topology optimization. Finite element based modal analysis was performed to identify

2- Step 2 Designing the fixed metallic support

To limit the patient mobility and secure it within ambulance space, a fixed metallic bed is being introduced. Two important characteristics are being targeted, modal analysis shifting to the safe operating vibrational range and reducing weight with minimizing stress concentration in order to maximize, the structure lifespan.

3- Step 3 Auxiliary systems spongy back support

The basic shape of the spine is a combination of curves, vary in gradually in thickness and radius. To give more support to the spine in transportation phase, a spongy back sport is designed to withstand back weight and adopted with its shape. The design objective is to minimize weight, with maximizing bulk modulus. To this goal, inverse homogenization based topology optimization technique is used. Homogenization technique is used for calculating effective properties in a wide spectrum of physics application, such as astrophysics, and mechanical engineering. This work uses the implementation of homogenization in composite materials calculations.

APPLIED DESIGN PROCESS

Materials in use

The mechanical characteristics of composite is summarizing in Table 1 and 2

Table 1. Mechanical properties and cost of carbon and glass fiber - epoxy system

Orthotropic Properties	Glass Fibers	Carbon Fibers
Ex	22.3e9 Pa	70.4e9 Pa
Ey	6.8e9 Pa	10.3e9 Pa
Ez	6.8e9 Pa	10.3e9 Pa
υ12	.35	.3
υ23	.4	.29
υ13	.35	.28
G12	2.8e9 Pa	7.17e9 Pa
G23	2.72e9 Pa	7.17e9 Pa
G13	2.8e9 Pa	10.1e9 Pa
Density	2.5e3 Kg/m³	1.6e3 Kg/m³
cost	10 $	105 $

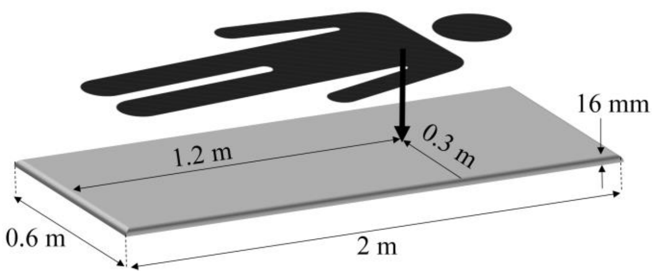
Table 2. Mechanical properties of secondary systems materials

Isotropic Properties	Aluminum	ABS
E	70e9 Pa	44e9 Pa
υ	.3	.34
Density	2.8e3 Kg/m³	1.04e3 Kg/m³

Design mobile cot part

The design problem is consisting of three parts, mobile cot made of a composite plate of dimensions (2 by .6 m). it consists of 8 plies of thickness 2 mm for ply. Ply has the possibility to be a unidirectional carbon fiber epoxy system or unidirectional glass fiber epoxy system. Orientation angle is varying between 0 and π angle. The cost of manufacturing ply of glass fiber composite is 10 $ while it is more than 10 times that for carbon fiber epoxy composite **(Table 1)**. A genetic algorithm was used to give the preliminary design of the mobile cot. the preliminary design boundary conditions are simply supported plate with the eccentric concentrated load.

Figure 3. Initial design problem of the mobile hybrid composite cot.



Weighted sum function is used as Multi-objective optimization function. Selection of weights for is vital for global optimality to be satisfied. GA is adopted as global optimization solver to select the best weighting for sum multi-objective function. It can be selected using an evolutionary algorithm with pre-determined sets by initialization of GA. The real coding genetic algorithm was used. GA is used successfully for the more complex problem, yet reasonable constraint numbers. Designing scheme is

$$\begin{aligned} &\min, w_1(\Im) + w_2(\Re) + w_3(\aleph) \\ &s.t. \quad ply \in [1,2] \\ &\qquad \theta \in]0, \pi[\end{aligned} \qquad \ldots 13$$

Here, $\Im$, is the weight of the designed plates, $\Re$, is the price of the design plates, and $\aleph$, is the maximum lateral displacement of the plates. Genetic algorithm designed plate is shown in Table 3.

Table 3. Generated optimal Preliminary mobile cot design using GA

Ply number	Composite system	Angle of orientation (degree)
1	Carbon epoxy	161
2	Glass epoxy	22
3	Glass epoxy	40
4	Carbon epoxy	129
5	Carbon epoxy	117
6	Glass epoxy	153
7	Carbon epoxy	23
8	Carbon epoxy	173

A model using finite element method is built to using ANSYS to identify natural frequencies within working vibration range. Suitable working vibration range has been adopted for between the range [0, 250] (Ref. 31-33). It shows the range of natural modes as in Table

Table 3. Modal analysis of GA design plate.

Mode	Frequency (Hz)
1	132.32
2	172.55
3	238.49

Shape optimization was used to multi-stage optimization of the hybrid composite plate. The first step is reducing the weight with maximizing lateral displacement with actual body load by free resizing of ply thickness. Topology optimization performed using OptiStruct solver. The optimization scheme of ply thickness is done by minimizing overall compliance of plate, with displacement and volume fraction as a constraint.

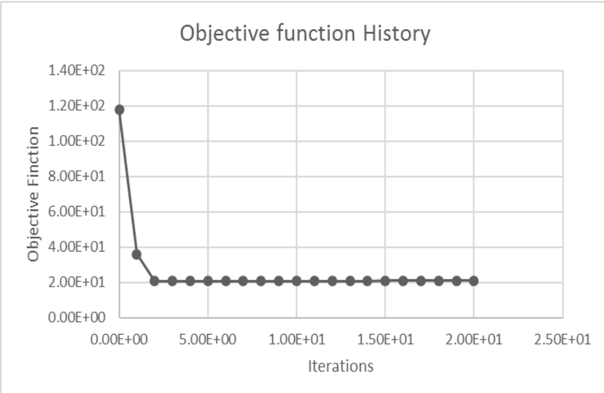
$$find \quad h \qquad \ldots 14$$

$$\min., F^T U \,|E_{mat\to 1} + x^p (E_{\min\to 0} + E_{mat\to 1})$$

$$s.t. \begin{cases} \int_{\Omega_d} \rho dx \le V_d., \; 0 < x_{\min} < x_e < 1 \quad \forall x \in \Omega_d \\ \lim W \to 0 \end{cases}$$

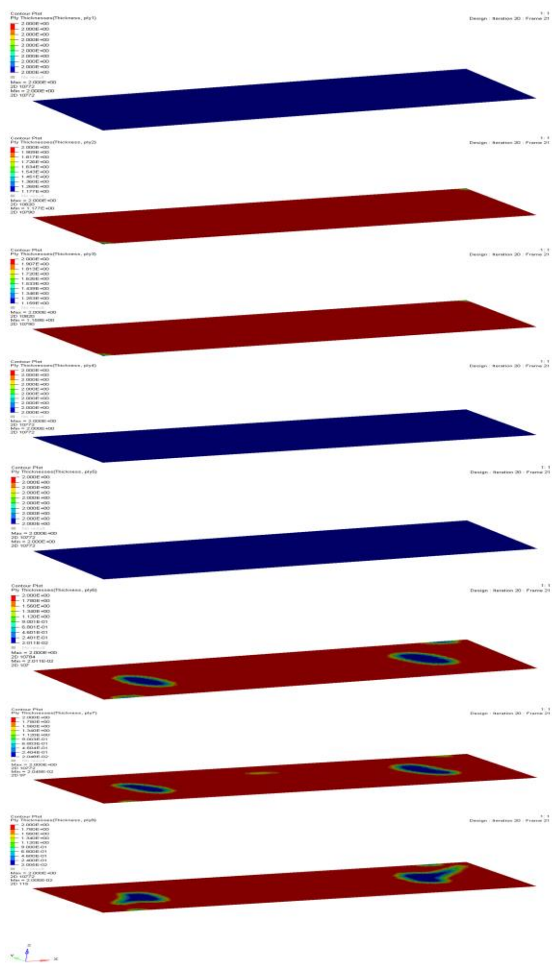
Objective function history is shown in figure 4

Figure 4. Shape Optimization objective function.



The designed ply thickness is shown in figure 5

Figure 5. Shape optimization ply design.



The results of modal analysis of newly generated plate are

Table 4. Modal analysis of shape optimization design plate.

Mode	Frequency (Hz)
1	144.6812
2	197.4815

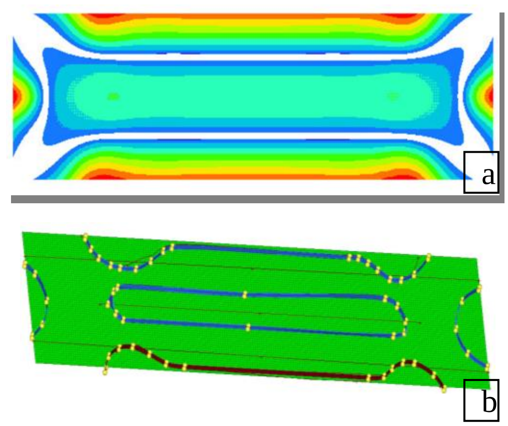
Designing a stiffener combination is preferable to support the plate.

$$\min.\sqrt[2]{\left(\sum_{e=1}^{M} w_c \frac{C_e - C^{\min}}{C^{\max} - C^{\min}}\right)^2 + \left(w_\omega \frac{\omega^{\max} - \omega_e}{\omega^{\max} - \omega^{\min}}\right)^2} \quad \ldots 15$$

$$s.t.\ s.t.\quad \int_{\Omega_d} \rho dx \le V_d\,,\ 0 < x_{\min} < x_e < 1 \quad \forall x \in \Omega_d$$

Here, C_e, $C^{\min}$, and $C^{\max}$ are structure compliance, lower bound, upper bound respectively. And the same for natural frequency.

Figure 6. Shape optimization based stiffener design, (a) optimization thickness results, (b) the designed stiffener based on scheme a



The modal analysis of final designed mobile cot is listed in table 5

Table 5. Stiffened mobile cot modal analysis

Mode	Frequency (Hz)
1	225.773
2	234.435
3	249.846

DESIGN METALLIC FIXED BED

The Aluminum bed was boundary conditions is as shown in Figure (7-a). The assumed design for which the boundary condition was taken is a plate supported by two cantilevers on the ends of the plate. Table 6 shows the modal analysis of the Aluminum bed

Table 6. Modal analysis of Aluminum Plate with block rigid support

Mode	Frequency (Hz)
1	41.28567
2	55.1153
3	114.2948
4	156.2364
5	178.224

The range of the first mode could be modified by introducing stiffener to the plate. To design optimal stiffener, design scheme in using equation 15 is been adopted. Results are shown in Table 7 (Figure 7-b).

Table 7. Modal analysis of Aluminum Plate with stiffener

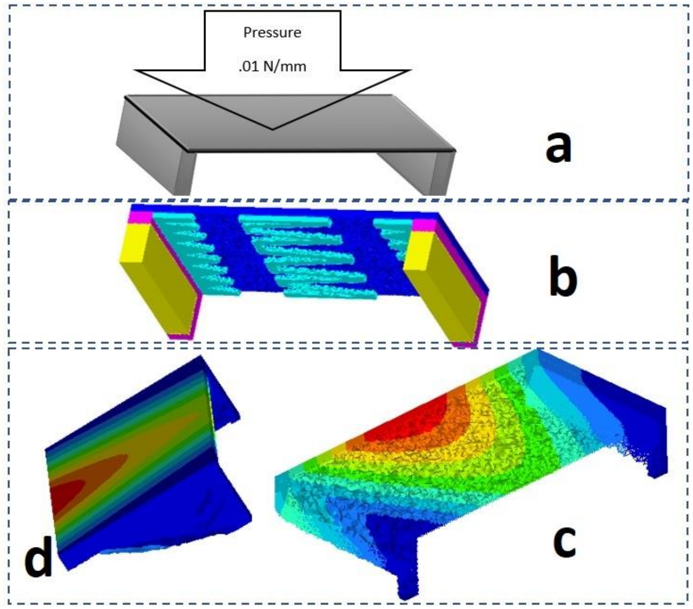
Mode	Frequency (Hz)
1	100.005
2	118.7942
3	150.5186
4	150.5202

Stress base CLS and free stress based - shape topology optimization was adopted to decrease support weight with maintaining feasibility of the support structure. Stress that targeted is von mises stress. Adjoint sensitivity was used for optimality criterion Stress results and displacements promote free shape topology optimization as shown in Table (8).

Table 8. Topology optimized of support results with 0.3 volume fraction design

Mode	Displacement (mm)	Stress (N/mm^2)
CLS	9.293e-2	1.933
Free shape	5.767e-2	1.188

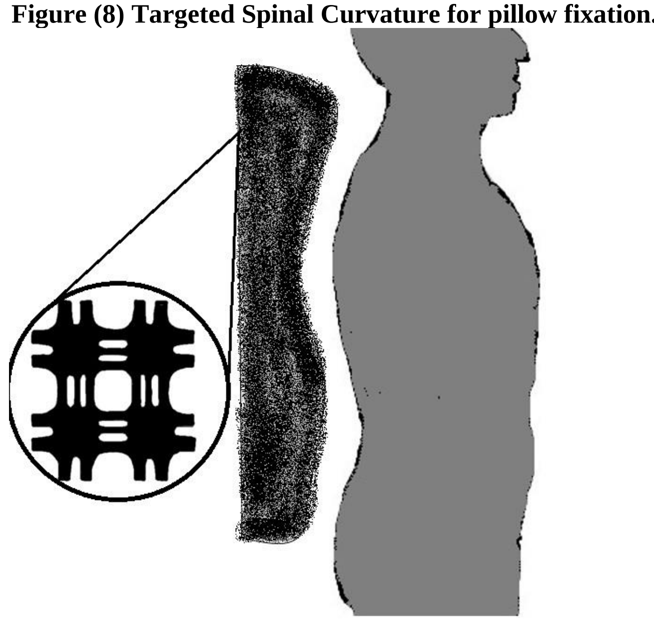
Figure 7. (a) designed problem, (b) stiffened metallic bed, (c) optimized support using CLS, (d) optimized support with Free shape optimization.



DESIGN SUPPORT PILLOW (MICRO STRUCTURE EXTREMUM WITH TOPOLOGY OPTIMIZATION)

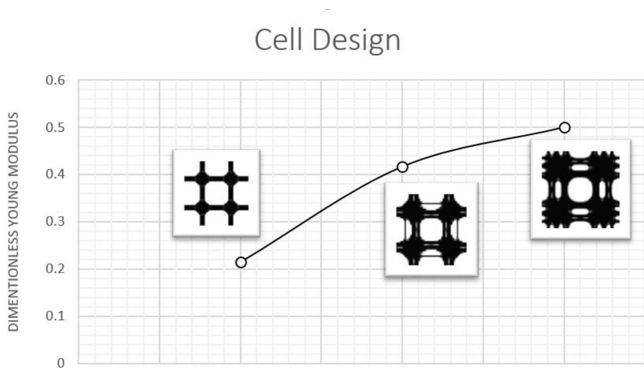
Securing spine needs active and passive systems. Active systems are the strips and belts that secure the body in order to limit inertia action of the human body. In most cases, it is possible to take advantage of the spinal creature.

Figure (8) Targeted Spinal Curvature for pillow fixation.



Pillow is design optimized for minimum weight and maximum bulk modulus of elasticity. Cellular composites are being considered here as an optimization strategy. It consists of the self-repeated optimized unit cell. Hashin-Strikman bounds are used to estimate the local bulk modulus. The optimized unit cell is being shown in Figure 9

Figure 9. Unit Cell optimization



Optimization algorithm is given in equation 16

$$\sigma = C : \varepsilon$$

$$\min(C_{11} + C_{22} + C_{12})|$$

$$C^{H}_{ijkl} = \frac{1}{|Y|}\sum_{e=Y}(d_0^{e(ij)} - d^{e(ij)})^T k^e(\rho^e)(d_0^{e(kl)} - d^{e(kl)})$$

$$K(\rho^e)d^{(ij)} = f^{(ij)}$$

… 16

Young modulus of elasticity can be found from equation (17)

$$E = \frac{(1+\upsilon)(1-2\upsilon)}{(1-\upsilon)}C_{11} \qquad ...17$$

CONCLUSIONS

In this paper, the superposition way of thinking is being adopted in the design process. Composite plate optimization was performed maximizing modal shape vibration. The results improved 8.5 % compared to initial, non-optimized plate. Designing stiffener improved vibrational response by 35% comparing to shape optimized ply design (Figure 10). The suggested stationary Aluminum bed will secure the patient with in the Ambulance designated space. Weight to performance ratio was approach by adopting stress based topology optimization objective function. 70% volume reduction as a constraint. Free shape topology optimization shows better results than CLS topology optimization with 38%. In order to shift the range of natural modes, stiffener design scheme was used, as same as for the mobile hybrid composite cot. The designed stiffeners show 59% improvement compare to non-stiffener one (Figure 11).

Figure 10. Free vibration analysis of mobile cot designs

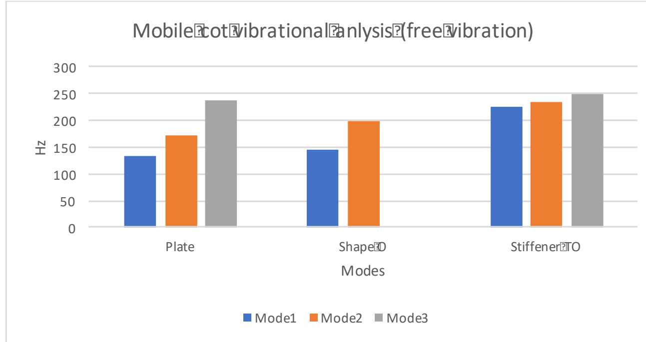
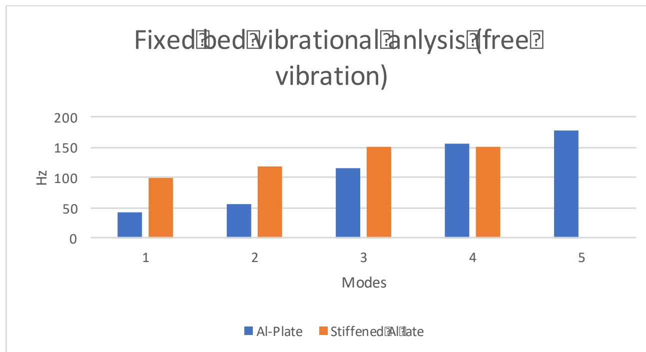


Figure 11. Free vibrational analysis of fixed bed designs.



In aeronautic designs, weight reduction is required. Pillow weight reduction was achieved by adopting inverse homogenization based topology optimization. Bulk modulus was chosen to be maximized.

Author contact:

Musaddiq Al Ali 1 mosadeq007@yahoo.com
Muazez Al ALi 2 drmuazez@gmail.com
Amjad Yusif 3 3dphotonic@gmail.com

ACKNOWLEDGMENTS

The authors would like to thank Dr. Abdil Khaliq Maleh Kadem, for his valuable information and knowledge sharing in spinal injury handling subject.

REFERENCES

[1]Blanco A., Delgado M., Pegalajar M. C. , "A real-coded genetic algorithm for training recurrent neural networks. Neural networks", 2001;14(1):93-105.

[2]Marler R. T., Arora J. S., "The weighted sum method for multi-objective optimization: new insights", Structural and multidisciplinary optimization. 2010;41(6):853-62.

[3]Le Riche R., Haftka R. T., "Optimization of laminate stacking sequence for buckling load maximization by genetic algorithm", AIAA journal. 1993;31(5):951-6.

[4]Liu B., Haftka R. T., Akgün M. A., Todoroki A., "Permutation genetic algorithm for stacking sequence design of composite laminates", Computer methods in applied mechanics and engineering. 2000;186(2):357-72.

[5]Park J., Hwang J., Lee C., Hwang W.,"Stacking sequence design of composite laminates for maximum strength using genetic algorithms",Composite Structures. 2001;52(2):217-31.

[6]Farshi B., Herasati S.,"Optimum weight design of fiber composite plates in flexure based on a two level strategy", Composite structures. 2006;73(4):495-504.

[7]Michell A. G. M.,"The limits of economy of material in frame-structures", The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science. 1904;8(47):589-97.

[8]Hemp W. S.,"Theory of structural design", College of Aeronautics Cranfield; 1958.

[9]Drucker D. C., Shield R.,"Design for Minimum Weight", BROWN UNIV PROVIDENCE RI; 1956.

[10]Chan A.,"The design of Michell optimum structures", College of Aeronautics Cranfield; 1960.

[11]Charrett D., Rozvany G.,"Extensions of the Prager-Shield theory of optimal plastic design", International Journal of Non-Linear Mechanics. 1972;7(1):51-64.

[12]Rozvany G., Prager W.,"Optimal design of partially discretized grillages", Journal of the Mechanics and Physics of Solids. 1976;24(2-3):125-36.

[13]Rossow M., Taylor J.,"A finite element method for the optimal design of variable thickness sheets", Aiaa Journal. 1973;11(11):1566-9.

[14]Cheng K. T., Olhoff N.,"An investigation concerning optimal design of solid elastic plates", International Journal of Solids and Structures. 1981;17(3):305-23.

[15]Bendsøe M. P.,"Optimal shape design as a material distribution problem", Structural and multidisciplinary optimization. 1989;1(4):193-202.

[16]Bendsoe M., Sigmund O.,"Topology Optimization-Theory, Methods and Applications", Springer; 2003.

[17]Sigmund O., Petersson J.,"Numerical instabilities in topology optimization: a survey on procedures dealing with checkerboards, mesh-dependencies and local minima", Structural and Multidisciplinary Optimization. 1998;16(1):68-75.

[18]Sigmund O.,"A 99 line topology optimization code written in Matlab", Structural and multidisciplinary optimization. 2001;21(2):120-7.

[19]Hill R.,"Elastic properties of reinforced solids: some theoretical principles", Journal of the Mechanics and Physics of Solids. 1963;11(5):357-72.

[20]Sanchez-Palencia E.," Homogenization method for the study of composite media", Asymptotic analysis II. 1983;985:192-214.

[21]Bensoussan A., Lions J. L., Papanicolaou G.,"Asymptotic analysis for periodic structures", North-Holland Publishing Company Amsterdam; 1978.

[22]Bendsøe M. P., Kikuchi N.,"Generating optimal topologies in structural design using a homogenization method", Computer methods in applied mechanics and engineering. 1988;71(2):197-224.

[23]Sigmund O.,"Materials with prescribed constitutive parameters: an inverse homogenization problem", International Journal of Solids and Structures. 1994;31(17):2313-29.

[24]Cadman J. E., Zhou S., Chen Y., Li Q.,"On design of multi-functional microstructural materials", Journal of Materials Science. 2013;48(1):51-66.

[25]Andreassen E., Andreasen C. S.,"How to determine composite material properties using numerical homogenization", Computational Materials Science. 2014;83:488-95.

[26]Gitman I. M., Askes H., Sluys L. J., Lloberas O.,"The concept of representative volume for elastic, hardening and softening materials", Proceedings of the XXXII International Summer School-Conference Advance Problems in Mechanics, Saint Petersburg (Repino), Russia; 2004.

[27]Hashin Z.,"Analysis of composite materials", J appl Mech. 1983;50(2):481-505.

[28]Hashin Z., Shtrikman S.,"A variational approach to the theory of the elastic behaviour of multiphase materials", Journal of the Mechanics and Physics of Solids. 1963;11(2):127-40.

[29]Castañeda P. P., Telega J. J., Gambin B.,"Nonlinear Homogenization and its Applications to Composites, Polycrystals and Smart Materials: Proceedings of the NATO

Advanced Research Workshop", held in Warsaw, Poland, 23-26 June 2003: Springer Science & Business Media; 2006.

[30]Choi K., Kuhn J. L., Ciarelli M. J., Goldstein S. A.,"The elastic moduli of human subchondral, trabecular, and cortical bone tissue and the size-dependency of cortical bone modulus", Journal of biomechanics. 1990;23(11):1103-13.

[31]Clevenson S. A., Leatherwood J. D., Hollenbaugh D. D., "Interior noise and vibration measurements on operational military helicopters and comparisons with various ride quality criteria". 1983.

[32]Konstanzer P., Enenkl B., Aubourg P., Cranga P., editors. "Recent advances in Eurocopter's passive and active vibration control",. annual forum proceedings-american helicopter society; 2008: american helicopter society, inc.

[33]Bongers P., Hulshof C., Dljkstra L., Boshuizen H., Groenhout H., Valken E.," Back pain and exposure to whole body vibration in helicopter pilots", Ergonomics. 1990;33(8):1007-26.