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OPTIMAL SIZING AND STACKING SEQUENCE OF COMPOSITE SKID LANDING GEAR OF A HELICOPTER

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ABSTRACT

In this paper, the design and optimization of skid landing gear for landing performance and gear strength. The composite skid landing gear is designed to replace usual aluminium 7075 skid landing gear using Kelvar49 epoxy, High modulus (HM) carbon/epoxy and AS4/8552 epoxy composites. A formulation and solution technique using a particle swarm algorithm (PSA) for design optimization of composite skid landing gear is obtainable. The reason of using PSA is to optimize and weight minimization of skid landing gear by considering the constraints such as angle of orientation, ply stacking sequence and ply thickness, taking aluminium alloy 7075 as base metal. The weight savings of the both composite skid landing gear have been calculated.

Keywords: Composite, Skid landing gear, PSA, Stacking Sequence

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1. INTRODUCTION

Fiber reinforced composite materials using in mechanical, aerospace, marine engineering and other branches has been heavily increasing. This possesses because of these materials better mechanical properties than other material like strength to weight, stiffness to weight ratios. Tailoring of such properties as the stacking sequence, fiber orientation and thickness of laminate in an anisotropic material provide unique opportunities, according to design requirement. The design may be optimized over different objective functions and design variables. Composite skid landing gear purpose has established new encouragement during the last decade. For the optimum design of composites researcher interested in weight reduction or composites should have more load carrying capacity for given thickness. Maintain layer orientation angles as well as the layer thicknesses are variables to optimize the strength[1]. Two stage optimization method developed by [2] discrete model for the optimization of universal composite plate, shell type structures subjected to random loading.[3][4] presented buckling studies for simply supported symmetrically laminated composite rectangular plate subjected to five dissimilar load conditions. The successive failure of different laminates subjected to a different loading situation has been treated by a layer-by-layer[5].[6]studied the split-Hopkinson bar to observe the dynamic properties of unidirectional, cross ply, angle ply laminates of IM7/977-3 graphite/epoxy composites under compressive loading. The laminated composite having first natural frequencies with different stacking sequences were calculated using the finite element method. Maximizes the first natural frequency by using genetic algorithm of the laminated composite plate defined as a fitness function (objective function) studied by [7][8].[9] showed that for a composite laminate plies having a different fiber angle in various directions for a given laminate thickness, the stacking sequence of the plies appreciably alters the degree of bend, twist coupling. [10] Describe the minimization of weight failure strength controlled composite structure, as well also formulated a composite lay-up design problem for minimizing the number of layers under strength constraints with respect to multiple loading conditions.[11] presents the new methodology to find inception of break, final failure and failure form of mechanically fastened joints in composite laminates able to calculate both the elastic limits of the joint, i.e., the load at which crack instigation takes place, and the ultimate failure load of the joint. Also, the method should be proficient to recognize the regular failure modes of composite bolted joints bearing, tension and shear. The most recent investigation in application of composite skid landing gear, in the year 2014 [12] conducted an experiment for design and structural analysis of skid landing gear and results were analyzed for different composite materials. [13] Presented a statistical approach to the optimization of skid landing gears, the basis of a genetic algorithm related to a multi-body explicit code. The modelling skill is described and numerical investigations performed on a gear prototype. [14] Effort has been made for design optimization of composite drive shafts for transmission of power. The formulation and solution method for design and optimization of composite drive shafts have been done using genetic algorithm. [15] Showed an optimization procedure to minimize thickness (or weight) of laminated composite plates subject to in-plane loading. Angle of fiber orientation and layer thickness are taken as design variables. Direct search, simulated annealing (DSA), this is a consistent, universal search algorithm is used to investigate the finest design.[16] used genetic algorithms (GAs) for the optimal design of symmetric composite laminates subjected to different loading and boundary conditions. To evaluate these laminates, using the shear deformation theory analyses has been done using the Finite element method.[17] maximize the failure strength of thin walled box-beam subjected to strength constraint for different loading, considering ply orientation angle are the design variables. The gradient based and particle swarm optimization method are used. [18] carried out ample precise model to assess the trim states of the helicopter and the optimization algorithm consists of an abhorrent particle swarm optimization program. A comparison with an evolutionary micro-genetic algorithm is also presented.

From the available literature it is clear that to evaluate the suitability of composite material such as Kelvar49 epoxy, High modulus carbon/epoxy and AS4/8552 epoxy for the purpose of aerospace landing gear applications is limited. Present work, helicopter skid landing gear has been designed optimally by using PSA for Kelvar49 epoxy, High modulus (HM) carbon/epoxy and AS4/8552 composite materials.The main investigation of this work is to minimize the weight of skid landing gear by taking stacks sequence, ply thickness and number of layers as variables.

2. STRUCTURAL STRENGTH

Under the limit load metal alloy skid landing gear are allowed to yield as per FAR Part 27. However, composites usually do not yield. Hence, sufficient strength must be displayed during take off and land scenarios. Appropriate failure theory would have to be established, below figure shows the 2D dimensions of Advanced light Helicopter skid landing Gear. The dimension of skid structure such as skid tube, forward cross tube, Aft cross tube damper assembly and abbression strip is measured and converted into a 3D model by using CATIA V19. Here considering two major components of the skid landing gear, two Skid tubes forward cross tube and Aft cross tube as the main weight saving components, we need to optimize to save the weight of skid landing gear of a Helicopter.

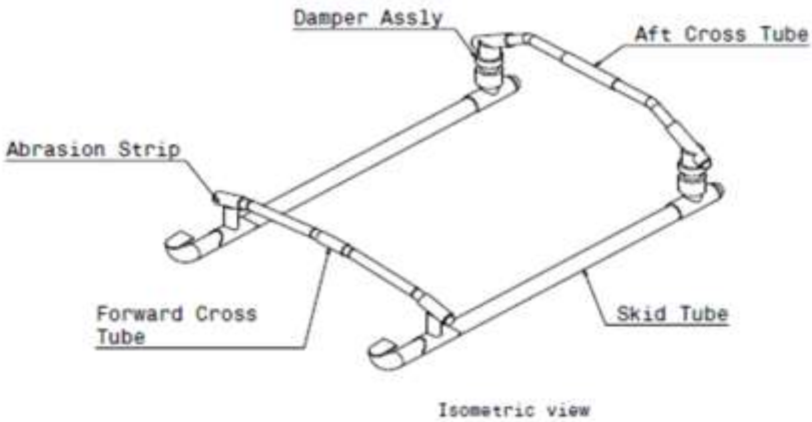

Figure 1 Skid landing Gear

3. SPECIFICATION OF THE PROBLEM

Skid landing Gear of a Helicopter is to sustain helicopter load up to 3400 kg and it becomes even more when Takeoff and Landing condition. So that skid tube should be strong enough to sustain different loading condition. According to Federal Aviation Regulation (FAR) landing gear should be designed such that, light weight design, corrosion resistance concerns in metal, as well as fatigue performance can be effectively addressed with the usage of composites. To design Advanced Light Helicopter(ALH) composite skid landing gear to optimize the weight, we have measured and taken as skid tube outer diameter d0 should be100mm and inner diameter di should be 90mm and total skid tube length required 8600mm (Two skid tubes and two cross tubes). The skid landing gear structure was designed efficiently for the particular design specification requirement [19].

4. DESIGN OF ALUMINUM 7075 ALLOY SKID LANDING GEAR

Presently aluminum 7075 alloy is used for making of skid landing gear. The material properties of the aluminum 7075 given in Table 1 [20]. For aluminum alloy skid landing tubes considering the number of ply is 48, orientation angle considered as 45º/90º /-45º /0º /-45º /0º /45º /90º /90º /45º /0º /-45º /0º /-45º /90º /45º /45º /90º /-45º /0º /-45º /0º /45º /90º]s and 10mm thickness thickness of aluminium skid landing gear having more weight than composite material because it is a metal alloy. Here we replace the composite material instead of aluminium alloy for the same number of ply, orientation angle and thickness to reduce the total weight of the skid landing gear.

Table 1 Mechanical properties of Aluminium alloy 7075

Mechanical properties	Symbol	Aluminum 7075
Young's modulus along longitudinal direction (GPA)	E_1	72
Young's modulus along transverse direction (GPa)	E_2	72
Shear modulus (GPa)	G	27.03
Poisson's ratio	ν	0.33
Density (Kg/m^3)	ρ	2700

4.1. Composite Skid Landing gear Design

The Kelvar49/epoxy, High modulus (HM) carbon/epoxy and AS4/8552 material are selected for composite skid landing gear. Table 2 shows the properties of composite material. E11 , E22, G12 , σT1, σC1 , σT2 and σC2 represent lamina properties in the longitudinal and transverse directions (Table. 2) respectively. ν12, τ12, ρ and Vf are the poisons ratio, shear stress and fiber volume fractions. Composite material properties that are differ along three mutually orthogonal two fold axes, rupture was not fully premeditated and factor of safety was taken as 2.

Table 2 Composite Materials mechanical properties

Property	Kelvar49 epoxy	(HM) carbon/epoxy	AS4/8552 epoxy
E_{11} (GPa)	76.0	190	151.4
E_{22} (GPa)	5.5	7.7	10.3
G_{12} (GPa)	2.3	4.2	7.0
ν_{12}	0.3	0.3	0.29
$\sigma^T_1 = \sigma^C_1$ (MPa)	1400	1600	1700
$\sigma^T_2 = \sigma^C_2$ (MPa)	53	54	95
τ_{12} (MPa)	34	30	76
ρ (kg/m^3)	1500	1600	1622
V_f	0.6	0.6	0.65

4.2. Design of Composite Skid Landing Gear in the Direction of Load aspect.

4.2.1. Analysis of stress, strains association for Unidirectional Lamina.

For a thin lamina, there is no out of plane load applied it can be considered as stress, strain relation for lamina under plane stress condition, hence it can reduce the 3D problem into the 2D problem. So that under plane stress condition can be written as

$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{Bmatrix} = \begin{bmatrix} R_{11} & R_{12} & 0 \\ R_{12} & R_{22} & 0 \\ 0 & 0 & R_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{Bmatrix} \quad (1)$$

Where $\sigma, \tau,$ and γ are represents stress and strain in material directions. The material under plane stresses and oriented along material axes can be simplified by defining new stiffness coefficient as:

$$R_{11} = \frac{E_{11}}{1-\nu_{12}\nu_{21}} \; R_{12} = \frac{E_{22}\nu_{12}}{1-\nu_{12}\nu_{21}} \; R_{22} = \frac{E_{22}}{1-\nu_{12}\nu_{21}} \; R_{66} = G_{12}$$

4.2.2. Stress-strain associations for lamina with uniformed direction

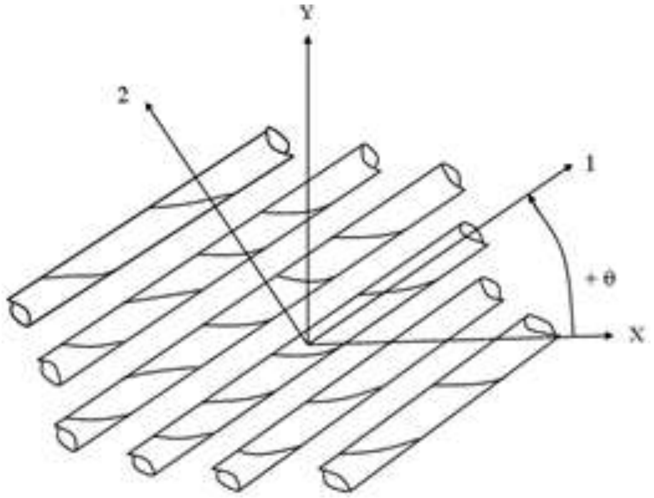

Figure 2 lamina with arbitrary orientation

The lamina having a orthotropic charactstics with its principal material axes oriented at an angle θ with the reference coordinate axes as shown in figure 2. Stress and strains relationship with respect to the reference coordinate system, the inplane stress component related to strain component as

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} = \begin{bmatrix} \overline{R_{11}} & \overline{R_{12}} & \overline{R_{16}} \\ \overline{R_{12}} & \overline{R_{22}} & \overline{R_{26}} \\ \overline{R_{16}} & \overline{R_{26}} & \overline{R_{66}} \end{bmatrix} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} \quad (2)$$

Where σ and ε represents the normal stress and strain in X,Y and XY directions. R_{ij} are the off-axis stiffness components which can be expressed in terms of principal stiffness components R_{ij}, by means of the tensor transformation rules [15] as

$\overline{R_{11}} = R_{11}\cos^4\theta + 2(R_{12}+2R_{66}) \sin^2\theta\cos^2\theta + R_{22}\sin^4$

$\overline{R_{22}} = R_{11}\sin^4\theta + 2(R_{12}+2R_{66}) \sin^2\theta\cos^2\theta + R_{22}\cos^4\theta$

$\overline{R_{12}} = (R_{11}+R_{22}-4R_{66})\sin^2\theta\cos^2\theta + R_{12}(\sin^4\theta+\cos^4\theta)$

$\overline{R_{16}} = (R_{11}+R_{12}-2R_{66})\sin\theta\cos^3\theta + (R_{12}-R_{22}+2R_{66})\sin^3\theta\cos\theta$

$\overline{R_{26}} = (R_{11}-R_{12}-2R_{66})\sin^3\theta\cos\theta + (R_{12}-2R_{66})\cos^3\theta\sin\theta$

$\overline{R_{66}} = (R_{11}-R_{22}-2R_{12}-2R_{66})\sin^2\theta\cos^2\theta + 2R_{66}(\sin^4\theta+\cos^4\theta)$

The principle stiffness expressions R_{ij} are associated elastic properties of the materials along the principal directions E_1,E_2,G_{12},ν_{12} and ν_{21}.Since the laminate is only subjected to inplane load and is symmetric.

5. DESIGN CONSTRAINTS

It enviable that the landing gear system provides required load carrying capacity, better strength, steadiness, under and over utilization of matrerial source, construction of failsafe design, etc. Main interest is composite skid landing gear is to obtain reduced weight skid landing gear under given useful constraint such as minimum thickness of ply,angle of orientation of ply and number of ply.For the best possible design of composite skid landing gear, variables measured with their restrictive values as shown in Table 3.

Table 3 Optimum design of various boundry conditions

Design Variable	Restrictive values of design variable
Ply number[n]	$n > 0$; $n = 1, 2, 3 \ldots 48$
Stacking sequence [θ_K]	$-90 \leq \theta_K \leq 90$; $K=1,2...n$
Ply thickness [t_k]	$0.10 \leq t_k \leq 0.50$

For weight minimization of composite skid landing gear, the objective function consider here is,

The weight of the skid tube:

$$w = \rho AL \text{ or } w = \rho\frac{\pi}{4}(d_0^2 - d_i^2)\, L_1 + L_2 \quad (3)$$

Where w = weight of the skid tube, ρ = density of the skid tube material, The d_i = inner diameter of the tube, do = outer diameter of the tube, and L = length of the tube. By modifying the objective function as $\Phi = m\ (1+k_1C)$, the controlled optimization can be changed to an uncontrolled optimization [21]. For all appropriate reason, k_1 is a penalty constant and is considered to be 10.

5.1. Particle Swarm Optimization algorithm operation

In the case of PSO each character in the particle swarm is unruffled of three dimensional vector, where D is the dimensionality of the search place. The conception of alteration to look for the points is shown in figure 3 with the current position X_{i+1}, the earlier best place X_i, and the velocity V_i. Every particle in the swarm is simplified using equations (4) and (5) at each iteration. PSO may have some unaffected character with genetic algorithms (GA), but it is much easier as it does not use alteration and intersect operators.

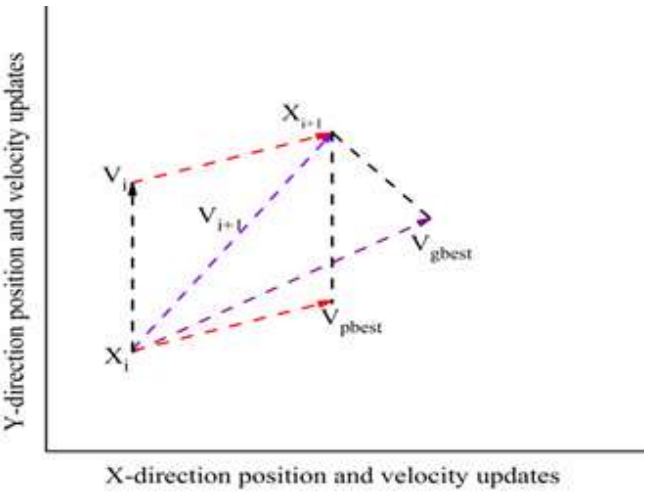

Figure 3 conception of alteration of a search point

In its place, it uses the real number uncertainty (encoding/decoding of the parameters not compulsory) and the common statement surrounded by the swarm particles. A variety of studies illustrate that PSO algorithms can do improved than genetic algorithms and other common solvers for solving several optimization problems. Mainly, particles are assigned by using a haphazard quantity, array and number of swarms of the specific population that is in use and the fitness function is estimated for each particle. From these fitness standards, the best value or the best of each swarm is established. While estimating for 150 swarms, 150 best values or pbests are obtained. Again from these pbests, the one universal best or gbest value is selected. The best particle or pbest in the swarm is push forward or modernized by using the PSOA's velocity and position as expressed in equations (4) and (5) as follows.

1. Initialize a population array of particles with disorganized positions and velocities on D dimensions in the search space. 2. Start of loop.
2. For each particle, estimate the preferred optimization fitness function in D variables.
3. Compare particle's fitness evaluation with its pbesti, if current value is improved than earlier pbesti, then set pbesti equivalent to the current value, and X_i equal to the present position X_{i+1} in D-Dimensional space.
4. Recognize the particle in the neighborhood with the finest achievement so far, and assign its catalog to the changeable gbest.
5. The following equation, we can Modify the velocity and position of the particle:

$$v[\,]=v[\,]w+ J_1 rand(\,)(pbest[\,]–present[\,])+J_2\, rand(\,)(gbest[\,]–present[\,]) \quad (4)$$

$$Present[\,]=present[\,]+v[\,] \quad (5)$$

The input parameters considered to PSOA are shown in the Table 4.

Table 4 PSOA parameters

Inertia weight, w	**vary in between 0.4 and 0.7**
arbitrary numbers, r_1 and r_2	vary in between 0 and 1
Leaning factors, J_1 and J_2	2
Number of Particle	50
Swarms size	150
Number of optimized variables	3

6. RESULT AND DISCUSSION

The program is developed and run using MATLAB 2017 to obtain best optimal values of skid landing gear. The approach consists of minimizing the weight of the skid landing gear. Flow chart explains the design algorithm of composite skid landing gear and method of optimizing the composite skid landing gear using the PSA algorithm as shown in Figures 4 and 5 respectively.

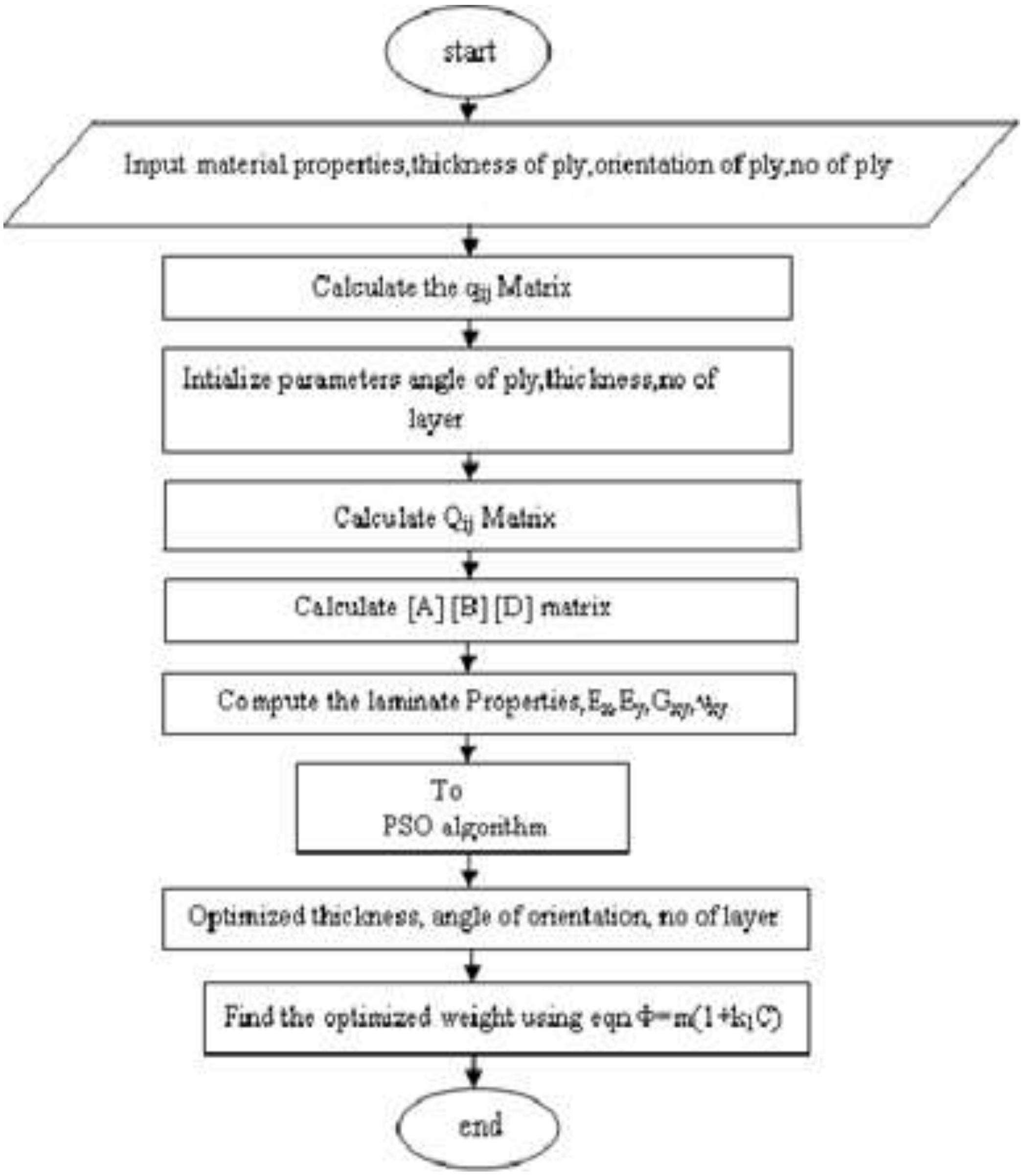

Figure 4 Design algorithm of skid Landing Gear

Select the material input parameter properties such as ply thickness(t_k), total ply number (n) and angle of ply orientation (θ_k). Initialize input parameters t_k =10mm, n =48 and θ_k =[45º/90º /-45º /0º /-45º /0º /45º /90º /90º /45º /0º /-45º /0º /-45º /90º /45º /45º /90º /-45º /0º /-45º /0º /45º /90º]s. Calculate reduced stiffness coefficient matrix (Q_{ij}) then calculate ABD matrix. Compute the laminate equivalent material properties E_x,E_y,G_{xy} and V_{xy} and then apply Particle swarm optimization to find the optimized ply numbers, optimized thickness and optimized ply orientation.

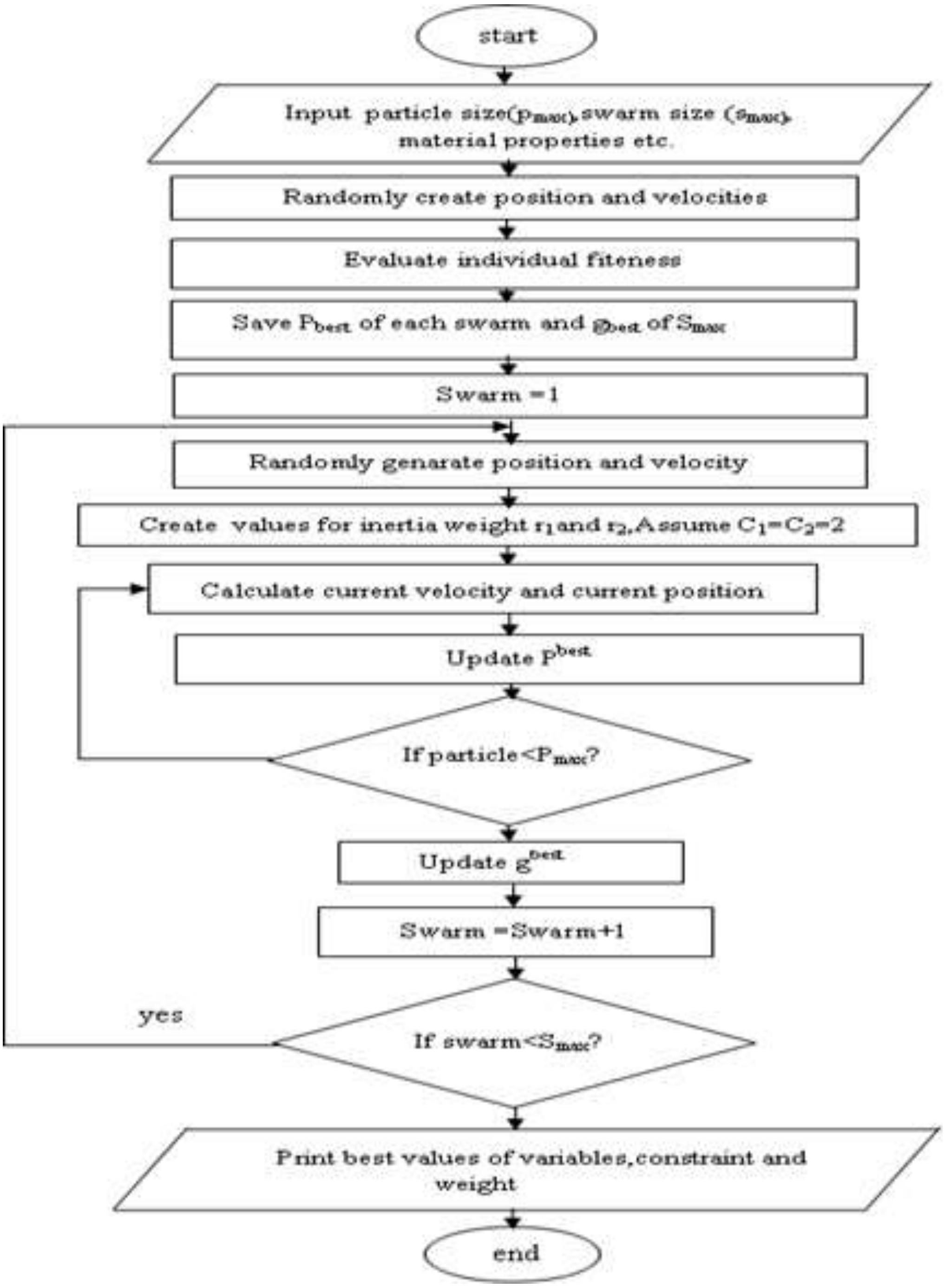

Figure 5 Flowchart of PSA based Optimal Design of Skid landing Gear.

The deviation of objective function values of Kelvar49/epoxy, High modulus (HM) carbon/epoxy and AS4/8552 epoxy skid tubes according to swarm size are shown in Figures. The variations of number of layers and ply thickness according to swarm size of the PSO are given in Figures 6 to14. For the first 125 swarm size of Kelar49 epoxy skid tube and 137 swarm size of HM carbon epoxy and AS4/8552 epoxy skid tubes, the weight is found to be fluctuating. The deviation is reduced to a smallest amount from generation numbers 125-140 in Kelar49 epoxy skid tube and 137 to 142 in HM carbon epoxy and AS4/8552 epoxy skid tubes respectively, and soon after they get converged.

The weight of the composite skid landing gear is directly interrelated to the number of layers and ply thickness. As the number of layers and ply thickness increases weight also increases, consequent fluctuations in weight, number of layers and ply thickness are seen in Figures 6 to 14. The optimum ply stacking sequence, optimum layers, optimum thickness and weight savings for Kelvar49 epoxy, HM carbon epoxy and AS4/8552 epoxy composite materials obtained from PSA is given in Table 5.

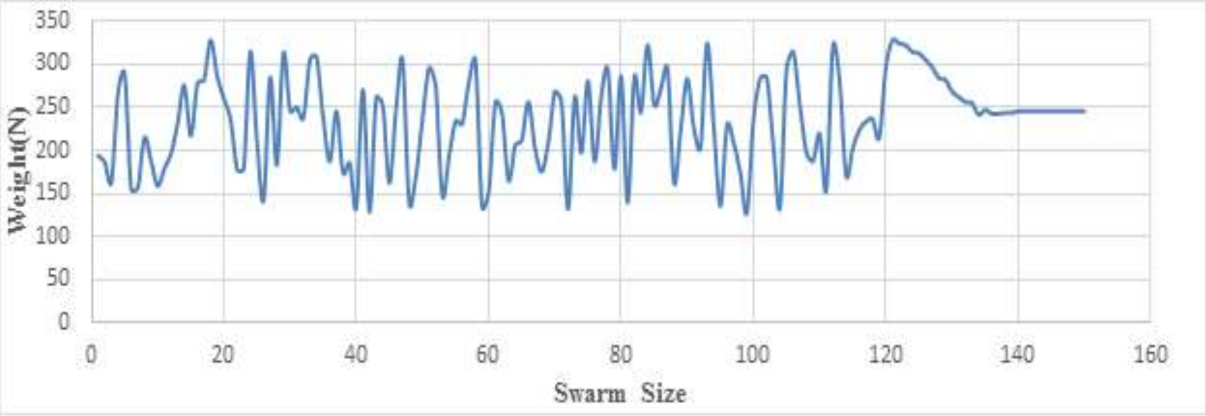

Figure 6 Variations of Mass of Kelvar49 Epoxy skid Tubes with Swarm Size

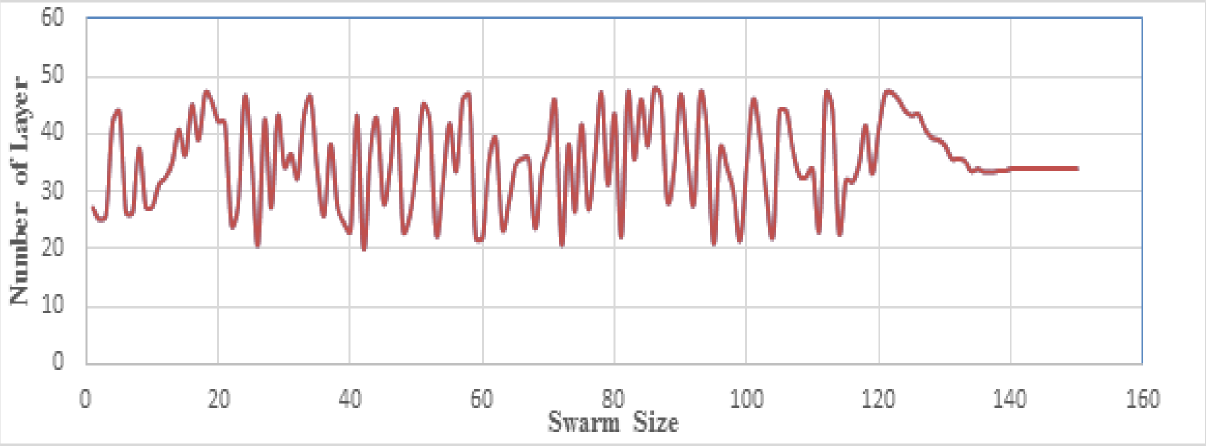

Figure 7 Variations of number of layers of Kelvar49 Epoxy skid Tubes with Swarm Size

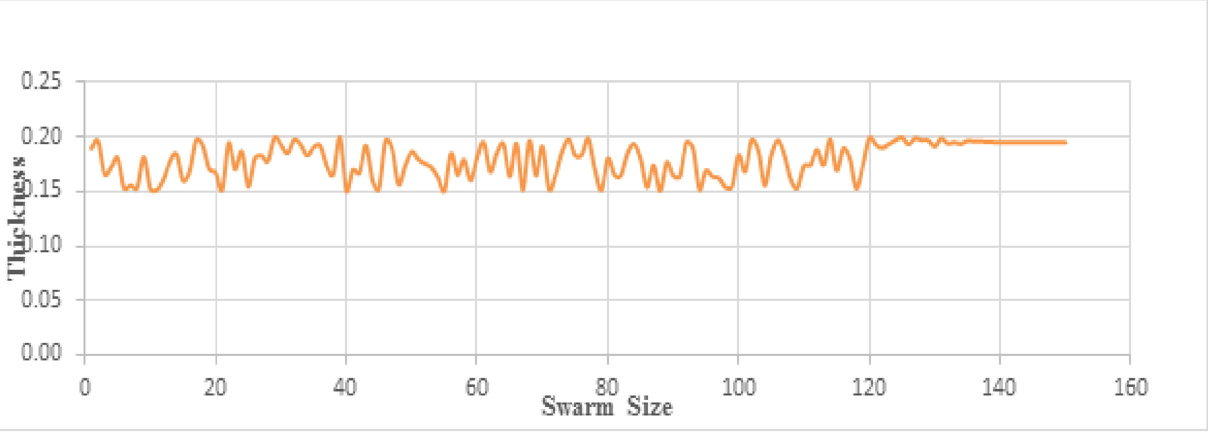

Figure 8 Variations of thickness of Kelvar49 Epoxy skid Tubes with Swarm Size

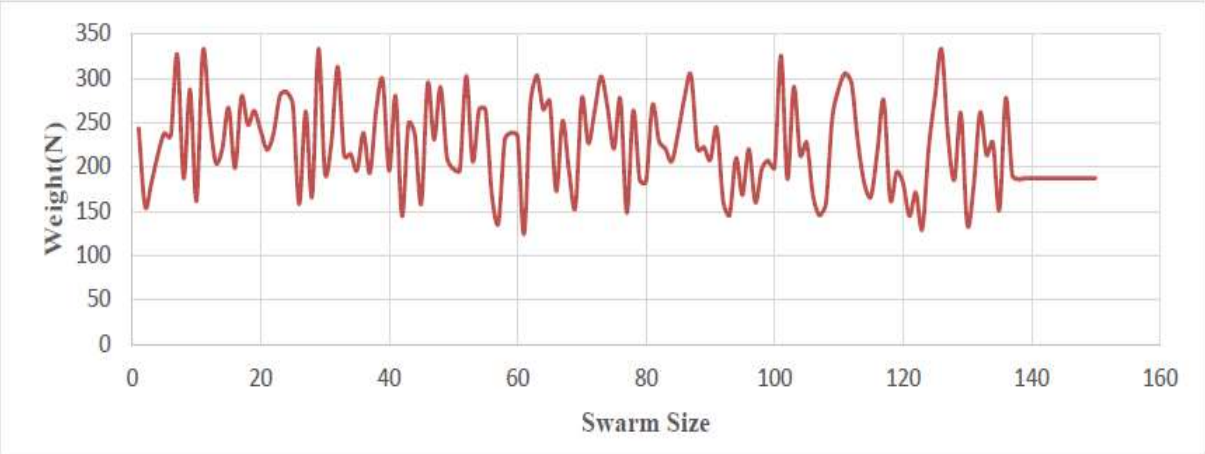

Figure 9 Variations of Mass of HM Carbon Epoxy skid Tubes with Swarm Size

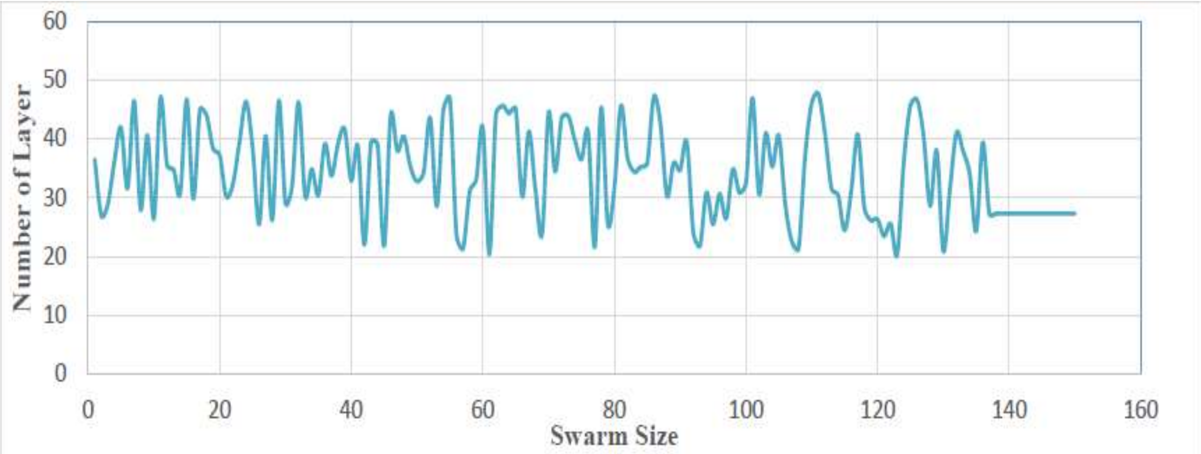

Figure 10 Variations of number of layers of HM Carbon Epoxy skid Tubes with Swarm Size

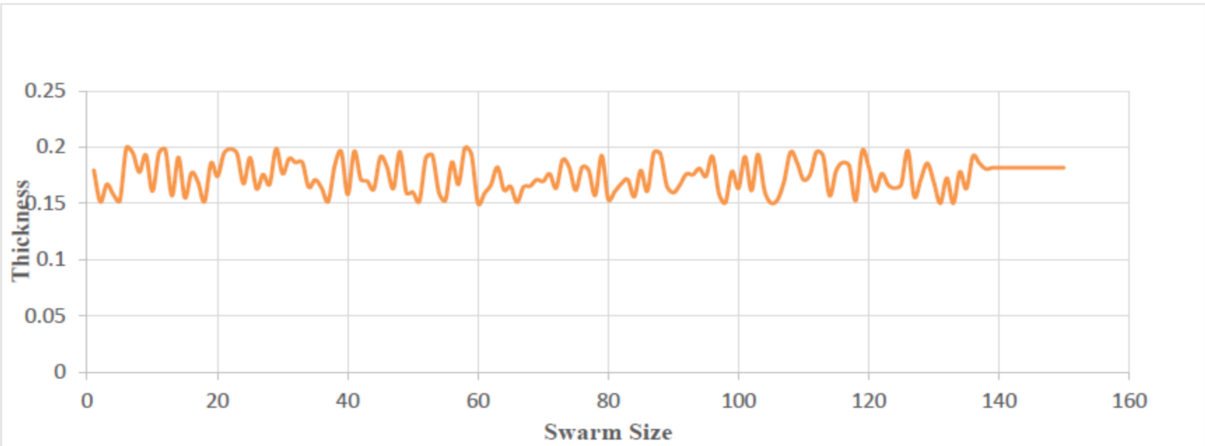

Figure 11 Variations of thickness of HM Carbon Epoxy skid Tubes with Swarm Size

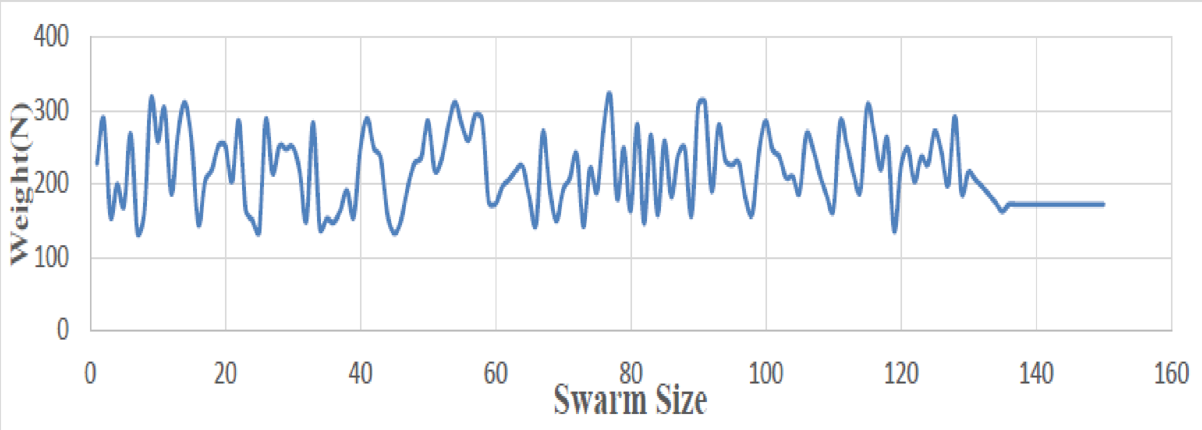

Figure 12 Variations of Mass of AS4/8552 Epoxy skid Tubes with Swarm Size

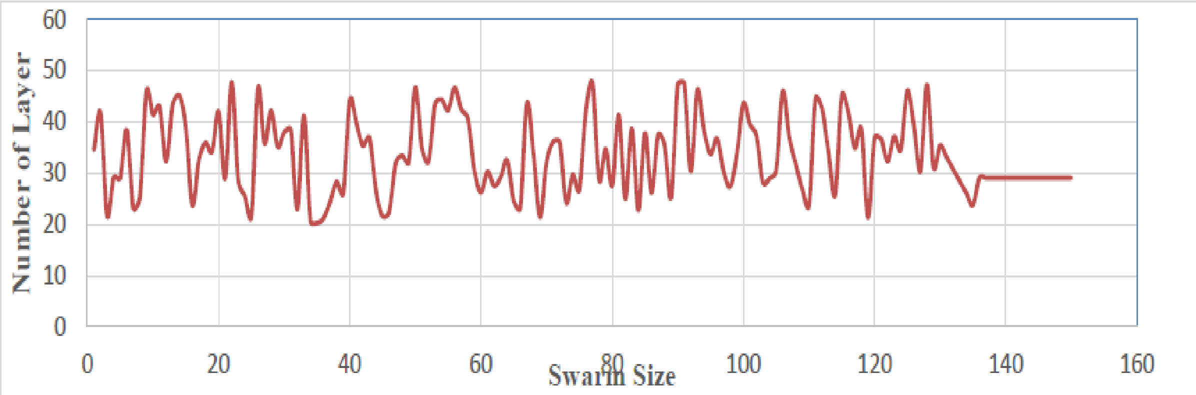

Figure 13 Variations of number of layers of AS4/8552 Epoxy skid Tubes with Swarm Size

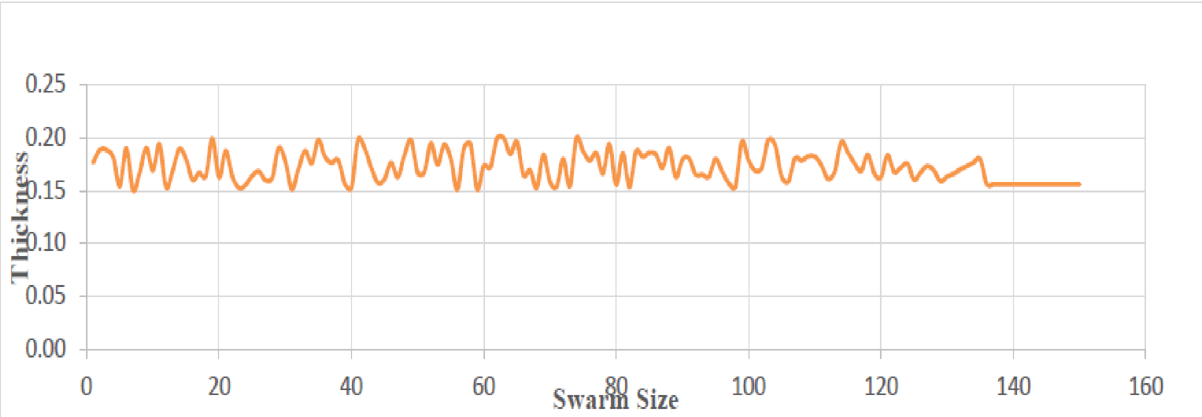

Figure 14 Variations of thickness of AS4/8552 Epoxy skid Tubes with Swarm Size

Table 5 Optimal design values of Aluminum 7075 alloy and composite skid tubes

Parameters	**Aluminum alloy 7075**	**Kelavr49 Epoxy**	**HM carbon Epoxy**	**AS4/8552 Epoxy**
d_0 (mm)	100	100	100	100
L (mm)	8600	8600	8600	8600
t (mm)	9.998	6.616	4.9032	4.5153
Optimum Layers	48	34	27	29
Thickness, t_k (mm)	0.2083	0.1946	0.1816	0.1557

Optimum Stacking Sequence	-	[-54/-24/-17/37/68/53/4/-35/-52/28/-79/1/87/60/12/87/-62] s	[81/-73/21/59/-14/-20/-69/19/-30/-42/-19/-84/56/51] s	[67/-51/73/-38/80/-24/-82/2/10/-70/23/-50/26/45/18] s
Weight (Kg)	65.653	25.046	19.099	17.522
Weight (N)	644.055	246.786	189.290	173.872
Weight saving (%)	-	61.682	70.608	73.003
* Taking Aluminum 7075 alloy weight as a datum				

7. CONCLUSION

In the present work optimization by PSA based Optimal Design of Skid landing Gear of a helicopter, the optimization has been done for three different constraints. The following conclusions can be drawn from the present work.

An optimization procedure is proposed to design a multilayered skid landing gear for a given number of ply, orientation angle and thickness to achieve minimum weight using PSA approach.Composite skid landing gear materials of Kelvar 49 epoxy, HM carbon epoxy and AS4/8552 epoxy are provide for composite skid landing gear in aerospace application.An optimal stacking sequence is generated using PSA to reduce the weight to meet the efficient and performance requirements. Appreciable percentage of weight savings have been founded by using PSA, so that composite material can be used in aerospace skid landing gear applications, there is no advantage to use any composite material having low stiffness in skid landing gear application because the percentage of weight saving is less.We can observe that number of ply and thickness of ply, play a vital role in a weight saving of skid landing gear, increase number ply and their thickness percentage of weight saving decreases.

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