Design of Composite Layup Tool for Horizontal Stabilizer Spar of Advanced Light Helicopter

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Abstract: The composite materials has extensive applications in the field of aerospace because of high strength to weight ratio. The spar is one such composite structural component of horizontal stabilizer which is located at the rear end of the helicopter. The spar resists the bending, twisting and axial loads on the stabilizer during flight there by maintaining the pitch of the helicopter at a set altitude. The spar is a sandwich composite manufactured by laying up of carbon epoxy prepregs. To carry out the layup of prepreg a layup tool is required. The layup tool material selection is an important aspect in manufacture of spar. The layup tool must have low weight to enable easy handling during layup activity and Coefficient of Thermal Expansion (CTE) of the tool is to be matched with that of the spar as to reduce the effect of stress build up due to differential expansion.

Index Terms **- Spar, Horizontal stabilizer, Carbon epoxy prepreg, Layup tool, Weight, Coefficient of Thermal Expansion.**

I. INTRODUCTION

The aerospace sector is one which uses composite structures extensively as they have high strength to weight ratio. Thermal expansion of composite laminates by M.N. Velea [1] focuses on development of an optimization model based on micromechanics theory of composite laminates where the ply angles represent design variables while objective are represented by thermal expansion coefficient of the laminate. Determination of thermal expansion coefficients for unidirectional fiber-reinforced composites was done by Ran Zhiguo et al. [2] where in the coefficients of thermal expansion of unidirectional fiber-reinforced composites are studied by means of thermo-elastic mechanics analysis. Modeling and Analysis of Ribs and Spar of an Airplane by Parthasarathy [3] explains the design of rib and spars to resist twisting, bending and axial loads in terms of size, shape for a particular material considering engine mountings, landing gear, fuel tank attachments in addition to external aerodynamic loads. Using MATLAB to Design and Analyze Composite Laminates by Avinash [4] showed how deal with the generation of MATLAB script files that assists the user in the design of a composite laminate to operate within safe conditions. The inputs of the program are the material properties, material limits and loading conditions. Static Stress Analysis and Normal Mode Analysis of Horizontal Tail Structure by Shashikant [5] focuses on analyzing the static stresses in the tail structure of the aircraft using different materials for skin. In the present work an attempt has been made to design and develop a composite layup tool for manufacturing spar of horizontal stabilizer considering the weight and CTE aspects.

II. HORIZONTAL STABILIZER SPAR OF ADVANCED LIGHT HELICOPTER

The horizontal stabilizer, also called the tail plane is present on the rear side of the plane and is used to stabilize the pitch of the helicopter i.e. tilting up or down of the helicopter and hence to provide stability to helicopter to keep it flying straight at set altitude.

The spar of the horizontal stabilizer is the load carrying member which resists the bending, torsional and axial loads there by providing the necessary strength to the horizontal stabilizer. The spar component is made up of composite material so as to keep the weight minimum and provide maximum strength. The spar is an I-section sandwich composite having a honeycomb core between the webs and covered over by the flange at the top and bottom side. The webs and flange part of the spar section is made by layup process, i.e. by laying up of carbon prepreg layers one above another up to required thickness on the layup tools, these layup tools are to be brought together and cured in the autoclave at predetermined pressure and temperature to produce the spar component required for the helicopter.

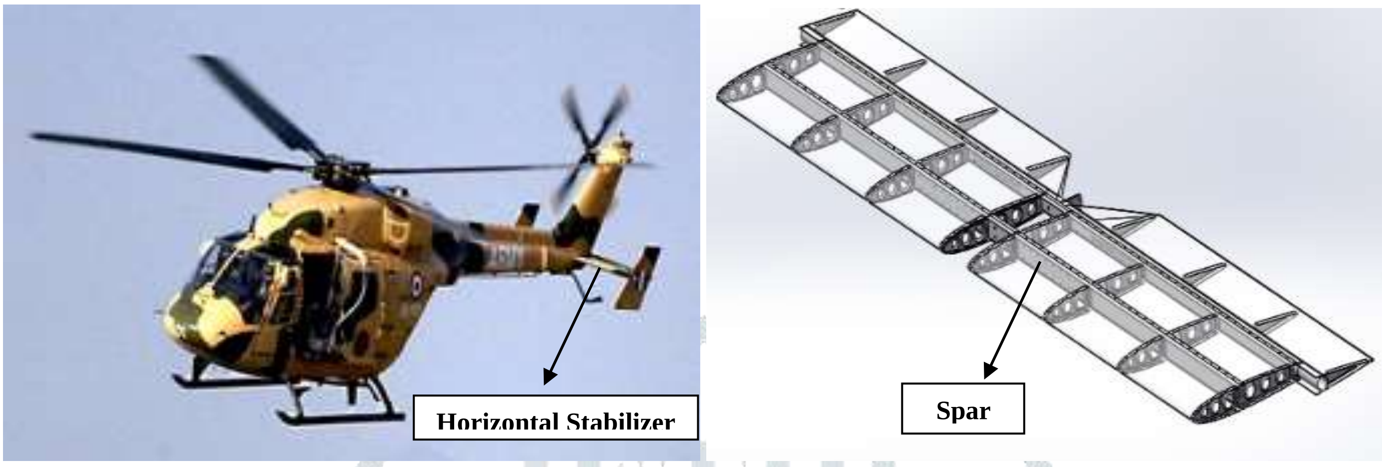


Figure 2.1: The horizontal stabilizer and its sectional view showing spar

III. LAYUP TOOL FOR SPAR

Generally the layup tools are made of metals like Aluminium, Steel, Invar or Nickel as they are easily available at affordable costs in required size and shapes. But, for the case of spar which is about 3m long, the layup tool weight is an important factor to be considered to facilitate easy work handling and also there is a necessity to match the coefficient of thermal expansion (CTE) of the layup tool with that of the component. The layup tools made of Steel, Aluminium and Composite material (Carbon epoxy) are compared with one another for weight and thermal expansion during cure cycle.

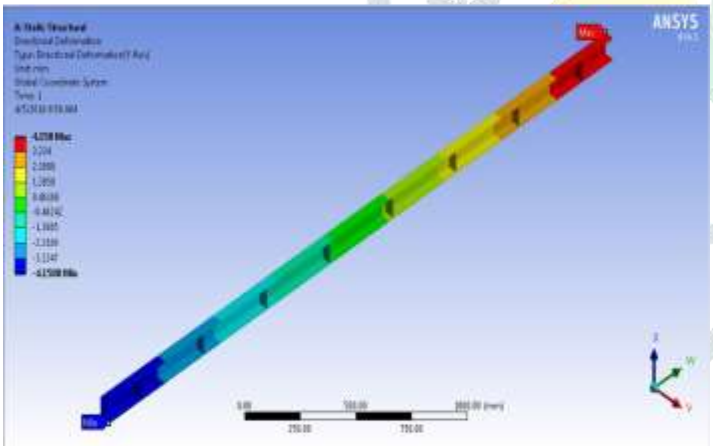


Figure 3.1: Thermal expansion in aluminium web layup tool

Theoretical thermal expansion of aluminium tool

= length x CTE x change in temperature

= 3200 x (23x10^{-6}) x (135-22)

= 8.3168 mm

Ansys result for thermal expansion of aluminium tool = 8.316 mm

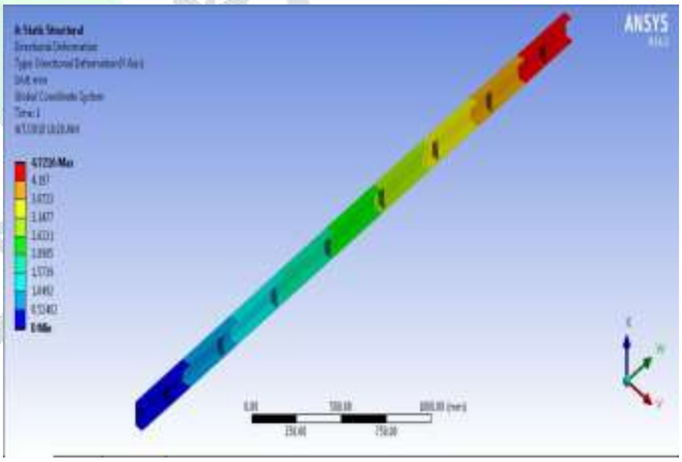


Figure 3.2: Thermal expansion in steel web layup tool

Theoretical thermal expansion of steel tool

= length x CTE x change in temperature

= 3200 x (13x10^{-6}) x (135-22)

= 4.701 mm

Ansys result for thermal expansion of steel tool = 4.7216 mm

The Composite layup tool is made from carbon prepreg (carbon in epoxy resin). The prepreg specification is LTM 217/CFT, where LTM 217 (Low Temperature Mould 217) represent the resin system which is low temperature, autoclave cured epoxy tooling system and CFT represent tool grade carbon fiber. To find the CTE of the composite laminate formed by above layup of plies, a Mat lab code is generated.

```
fprintf('COEEFFICIENT OF THERMAL EXPANSION OF LAMINATE LAYUP TOOL \n ')
fprintf('Enter the input data \n')
vf=input('Fiber Volume Fraction =');
vm=input('Matrix Volume Fraction =');
ef1=input('Youngs Modulus of fiber along fiber direction in MPa =');
em=input('Youngs Modulus of matrix in MPa =');
uf12=input('Poissons ratio of fiber  =');
um=input('Poissons ratio of matrix  =');
pf=input('Density of fiber in kg/m3=');
af1=input('Co-efficient of thermal expansion of fiber, in fiber direction=');
af2=input('Co-efficient of thermal expansion of fiber, perpendicular to fiber direction=');
am=input('Co-efficient of thermal expansion of matrix=');
fprintf('The local Co-efficient of thermal expansion for lamina are \n')
a1=(((vf*af1*ef1)+(vm*am*em))/((ef1*vf)+(em*vm)))
a2=((vf*af2)*(1+((uf12*af1)/pf)))+((vm*am)*(1+um))-(((vf*uf12)+(vm*um))*a1)
e1=input('Youngs modulus in longitudinal direction or fiber strength=');
e2=input('Youngs modulus in transverse direction=');
u12=input('Major Poissons ratio=');
g12=input('The inplane shear modulus=');
fprintf('The Minor Poissons ratio is')
u21=(e2*u12)/e1
fprintf('The stiffness values are')
q11=e1/(1-(u12*u21))
q22=e2/(1-(u12*u21))
q12=(e2*u12)/(1-(u12*u21))
q66=g12
fprintf('The Tsai-Pagano material invariants are')
u1=(1/8)*((3*q11)+(3*q22)+(2*q12)+(4*q66))
u2=0.5*(q11-q22)
u3=(1/8)*((q11)+(q22)-(2*q12)-(4*q66))
u4=(1/8)*((q11)+(q22)+(6*q12)-(4*q66))
u5=(1/8)*((q11)+(q22)-(2*q12)+(4*q66))
fprintf('The Thermal material constants are')
k1=((u1+u4)*(a1+a2))+(u2*(a1-a2))
k2=(u2*(a1+a2))+((u1+(2*u3)-u4)*(a1-a2))
k3=(u2*(a1+a2))+(((2*u3)+(2*u5))*(a1-a2))
n=input('The number of laminas in the laminate =');
h=input('The thickness of lamina =');
th1=input('The angle of fiber orientation in lamina 1 in radian=');
th2=input('The angle of fiber orientation in lamina 2 in radian=');
th3=input('The angle of fiber orientation in lamina 3 in radian=');
th4=input('The angle of fiber orientation in lamina 4 in radian=');
th5=input('The angle of fiber orientation in lamina 5 in radian=');
th6=input('The angle of fiber orientation in lamina 6 in radian=');
th7=input('The angle of fiber orientation in lamina 7 in radian=');
th8=input('The angle of fiber orientation in lamina 8 in radian=');
th9=input('The angle of fiber orientation in lamina 9 in radian=');
th10=input('The angle of fiber orientation in lamina 10 in radian=');
v0a=n*h
v1a=(h*cos(2*th1))+(h*cos(2*th2))+(h*cos(2*th3))+(h*cos(2*th4))+(h*cos(2*th5))+(h*cos(2*th6))+(h*cos(2*th7))+(h*cos(2*t
h8))+(h*cos(2*th9))+(h*cos(2*th10))
v2a=(h*sin(2*th1))+(h*sin(2*th2))+(h*sin(2*th3))+(h*sin(2*th4))+(h*sin(2*th5))+(h*sin(2*th6))+(h*sin(2*th7))+(h*sin(2*th8))
+(h*sin(2*th9))+(h*sin(2*th10))
v3a=(h*cos(4*th1))+(h*cos(4*th2))+(h*cos(4*th3))+(h*cos(4*th4))+(h*cos(4*th5))+(h*cos(4*th6))+(h*cos(4*th7))+(h*cos(4*t
h8))+(h*cos(4*th9))+(h*cos(4*th10))
v4a=(h*sin(4*th1))+(h*sin(4*th2))+(h*sin(4*th3))+(h*sin(4*th4))+(h*sin(4*th5))+(h*sin(4*th6))+(h*sin(4*th7))+(h*sin(4*th8))
+(h*sin(4*th9))+(h*sin(4*th10))
A11 = u1*v0a + u2*v1a + u3*v3a;
A22 = u1*v0a - u2*v1a + u3*v3a;
A12 = u4*v0a - u3*v3a;
```

```
A66 = u5*v0a - u3*v3a;
A16 = 0.5*u2*v2a + u3*v4a;
A26 = 0.5*u2*v2a - u3*v4a;
fprintf('The Extensional Stiffness Matrix is \n')
A = [A11 A12 A16; A12 A22 A26; A16 A26 A66]
fprintf('The Thermal Expansion Coefficients in Global coordinates\n')
alf_eqv = 0.5*A^(-1)*[k1*v0a + k2*v1a; k1*v0a - k2*v1a; k3*v2a]
```

OUTPUT:

```
COEEFFICIENT OF THERMAL EXPANSION OF LAMINATE LAYUP TOOL
 Enter the input data
Fiber Volume Fraction =0.6
Matrix Volume Fraction =0.4
Youngs Modulus of fiber along fiber direction in MPa =70000
Youngs Modulus of matrix in MPa =3500
Poissons ratio of fiber  =0.1
Poissons ratio of matrix  =0.33
Density of fiber in kg/m3=1600
Co-efficient of thermal expansion of fiber, in fiber direction=2.1e-6
Co-efficient of thermal expansion of fiber, perpendicular to fiber direction=2.1e-6
Co-efficient of thermal expansion of matrix=57.5e-6
The local Co-efficient of thermal expansion for lamina are
a1 = 3.8871e-06
a2 = 3.1104e-05
Youngs modulus in longitudinal direction or fiber strength=70000
Youngs modulus in transverse direction=3500
Major Poissons ratio=0.3
The inplane shear modulus=5000
The Minor Poissons ratio is
u21 = 0.0150
The stiffness values are
q11 = 7.0316e+04
q22 = 3.5158e+03
q12 = 1.0547e+03
q66 = 5000
The Tsai-Pagano material invariants are
u1 = 3.0451e+04
u2 = 3.3400e+04
u3 = 6.4653e+03
u4 = 7.5201e+03
u5 = 1.1465e+04
The Thermal material constants are
k1 = 0.4196
k2 = 0.1927
k3 = 0.1927
The number of laminas in the laminate =10
The thickness of lamina =0.6
The angle of fiber orientation in lamina 1 in radian=0
The angle of fiber orientation in lamina 2 in radian=0
The angle of fiber orientation in lamina 3 in radian=0.7854
The angle of fiber orientation in lamina 4 in radian=-.7854
The angle of fiber orientation in lamina 5 in radian=1.5708
The angle of fiber orientation in lamina 6 in radian=1.5708
The angle of fiber orientation in lamina 7 in radian=-.7854
The angle of fiber orientation in lamina 8 in radian=.7854
The angle of fiber orientation in lamina 9 in radian=0
The angle of fiber orientation in lamina 10 in radian=0
v0a = 6
v1a = 1.2000
v2a = -8.8157e-06
v3a = 1.2000
v4a =1.7631e-05
```

The Extensional Stiffness Matrix is

$$A = 1.0e{+}05 * \begin{matrix} 2.3054 & 0.3736 & -0.0000 \\ 0.3736 & 1.5038 & -0.0000 \\ -0.0000 & -0.0000 & 0.6103 \end{matrix}$$

The Thermal Expansion Coefficients in Global coordinates

$$alf\_eqv = 1.0e{-}05 * \begin{matrix} 0.4928 \\ 0.6377 \\ 0.0000 \end{matrix}$$

Thermal expansion of composite tool = length x CTE x change in temperature

= 3200 x (6.377×10^{-6}) x (135-22)

= 2.306 mm

IV. RESULTS AND DISCUSSION

The following table shows the weight, CTE and thermal expansion in Steel, Aluminium and Composite layup tools respectively

Sl No.	Material of Layup Tool	Mass (kgs.)		C.T.E ($\times 10^{-6}$/°C)	Thermal Expansion (in mm)	
		Web tool	Flange tool		Theoretical	Ansys
1.	Steel	29	16	13	4.701	4.7216
2.	Aluminium	10.4	6	23	8.316	8.316
3.	Composite	6.3	3.5	6.377	2.306	

Table 1. Comparison of materials for layup tool

From the above table it is clear that composite tool has low weight and low thermal expansion when compared to that of steel and aluminium. Hence a composite layup tool is designed for manufacturing spar. In order to manufacture a composite tool a master model is to be designed and developed first. A master model provides the necessary prepreg layup area for building the required thickness composite layup tool. Master model is made of epoxy blocks as it has easy machinability, high accuracy, stability for long time, no reaction with prepreg and capable of withstanding autoclave pressure and temperature.

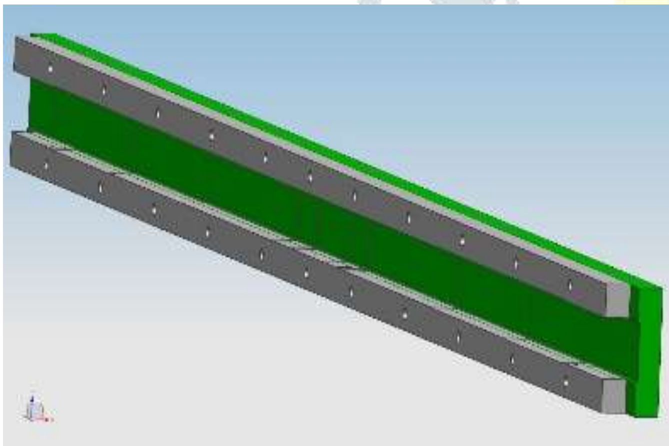


Figure 4.1: Left hand web layup tool master model

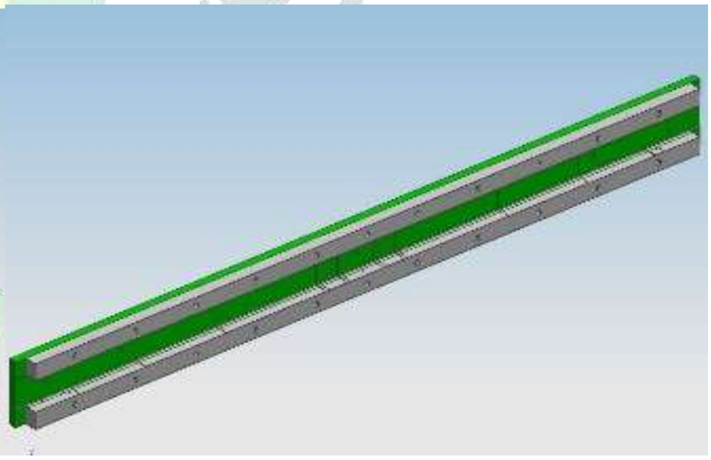
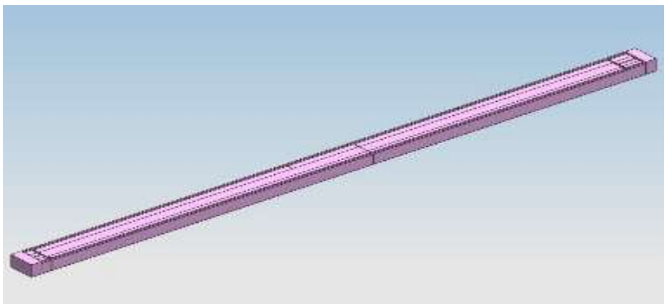


Figure 4.2: Right hand web layup tool master model



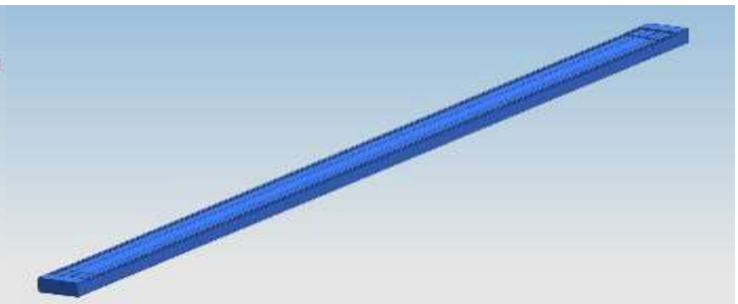


Figure 4.3: Top flange layup tool master model Figure 4.4: Bottom flange layup tool master model

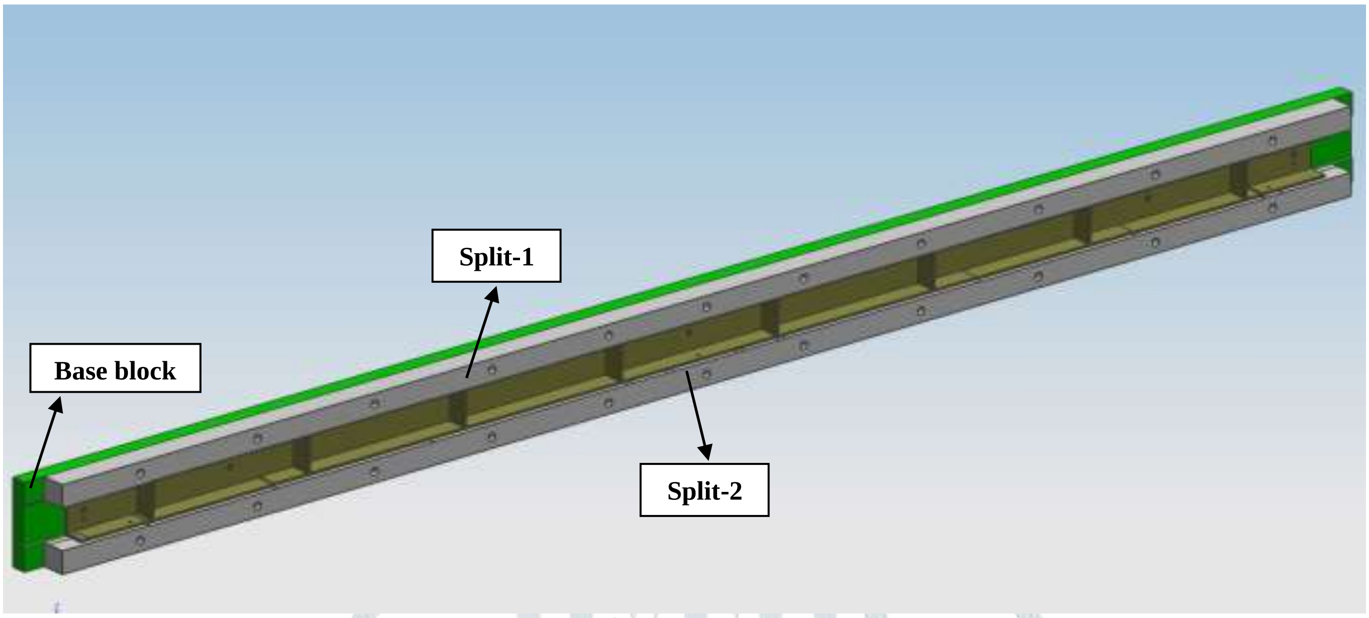


Figure 4.5: Master model with layup of prepreg

In order to facilitate easy demoulding of the web layup tools after curing process in the autoclave the master model is made split type, and these splits are held together by help of Allen screws.

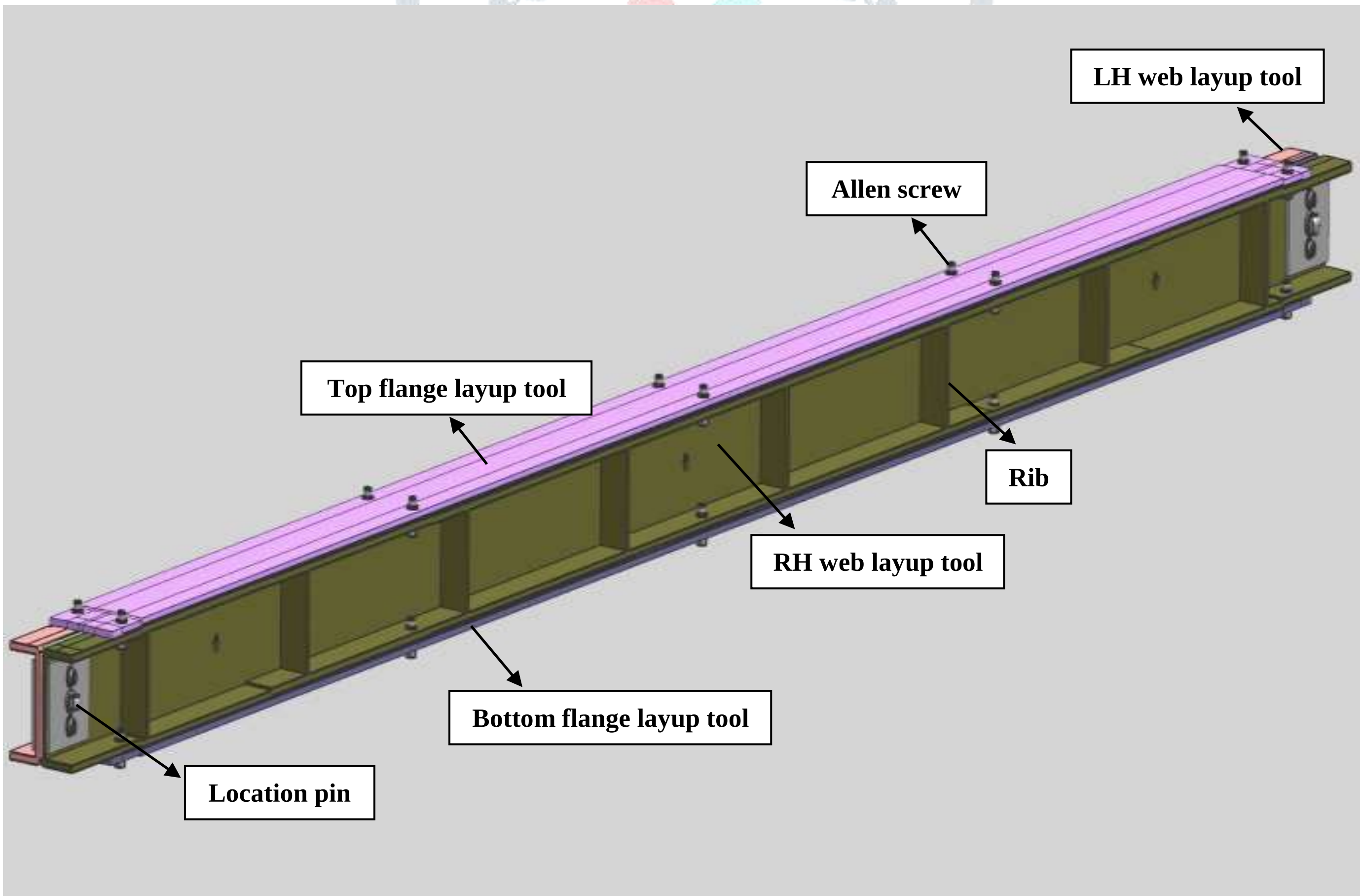


Figure 4.6: Layup tools on assembly for spar production

The layup tools are held together with in place with help of allen screws and nut. Spacers are provided between the LH and RH web tools at both front and rear side to prevent damage of tools during fastening. Also in order to make tool assembly fool proof i.e. to prevent wrong assembly, location pins of different diameter are provided at both front and rear ends. The place for layup process and for moving the assembly onto the autoclave a trolley is necessary. The complete assembly of layup tools along with the trolley is represented in the figure below.

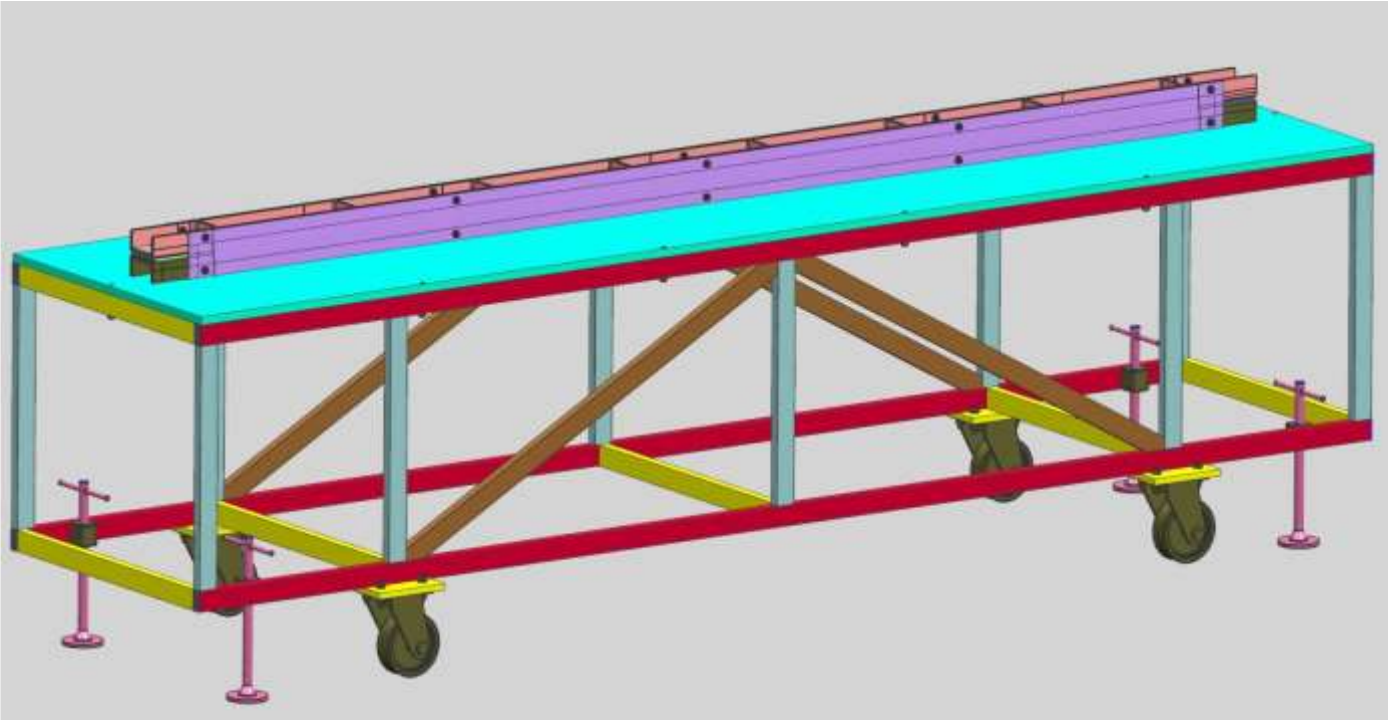


Figure 4.7: Layup tool with the trolley

V. CONCLUSIONS

Composite materials find their extensive applications in the field of aeronautics, since because of the high strength to weight ratio compared to any other materials. The spar of the horizontal stabilizer of advanced light helicopter is one such composite component, designing the layup tool for manufacturing spar was the task. Critical step is the selection of the layup tool material. The layup tool material selected must be light in weight to enable easy work handling and also coefficient of thermal expansion of tool material is to be matched with that of the spar component. Hence, layup tool was made of composite material. Following are some of the advantages of using the composite layup tool to produce spar:-

- The tool is easy to handle as it is light in weight.
- Dimensional stability is achieved.
- There is no mismatch in CTE.
- The tool is tailor able, different directions can be matched to the loads in those directions and contours can be easily achieved.
- Possibility of moulding composite profile and contouring is easy.

VI. REFERENCES

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