DESIGN A COMPOSITE MATERIALS LANDING GEAR

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Abstract. In the paper we present the project of a landing gear for an aerial target. It is presented the design of a low-cost and small mass landing gear for an aerial target by completing the resistance calculation and analysis with finite elements steps. The resistance calculation of the composite material landing gear models the stresses in laminate composite material through the lamina macro mechanics and the resistance theories applied to the composite sheet. Finite element analysis was done in a Finite Element Analysis program (Solids Works). The modeling is verified by experimental tests performed with the composite material landing gear. Experimental and theoretical deformations are compared for train requests at landing.

1. Introduction

The composite landing gear has several limitations. In the project, we have the goal to reduce as much as possible the mass of the landing gear to less than 1050 g as the train that the airplane are equipped. Also the reduction in train mass must not affect the stiffness of the train and its deformations to operating demands. The surface of the train shall be smooth so that the unmanned airplane with this landing gear at the maximum flight speed does not decrease the performance of the airplane. It is also intended to reduce the thickness of the train with influence directly to the decreasing its drag and mass. The landing gear shall be resistant to the same stresses during the take-off and landing procedures and during the unmanned airplane flight.

2. Establishment of operating conditions

The following requests can be identified:

- exposure to temperatures - in the range -13°C ÷ +40°C
- exposure to pressure - in the range 1 atm ÷ 0.78 atm
- exposure to moisture - the tread is used in conditions of high humidity and salinity
- exposure to benzine and synthetic oils
- mechanical vibration loads due to engine operation
- mechanical shocks at landing and take-off from the aerodrome runway
- the geometrical tolerances of execution are given by the hole tolerances for fixing the fuselage and the wheels in the tolerance field H6-H11. The lamination of the composite blank is executed...
in the precision class V for geometric tolerances of thickness and width. The finishing of the surfaces of the composite blank must be in the precision class m (according to STAS 2300-88).

- the propeller being propulsive and the main train of composite material being located near it, it must provide a sufficient height of the propeller disk to the ground during take-off and landing maneuvers.

3. **Geometry of the main landing gear**

Figure 1 shows the CAD model of a main landing train designed for a radio-controlled target aircraft prototype. Some components used for assembly, such as wheels, bolts, axes and nuts, have been ignored to simplify the model.

The geometrical characteristics of the prototype landing gear are as follows:

- **Height:** 320 mm
- **Gauge:** 650 mm
- **Width:** variable from 45 mm to 80 mm in the central area
- **Thickness:** variable from 5 mm at 9 mm to the center
- **Diameter of the holes on the fuselage:** 6.2 mm
- **Wheel bolt diameter:** 10.2 mm
4. Type of material
The main landing gear is made of composite material composed of the following elements: glass fiber, carbon fiber and epoxy resin. The combination of fiberglass and carbon fiber has been chosen for the following reasons: glass fiber provides elasticity, and carbon fiber provides the rigidity required for the landing gear, these properties being required on the ground impact when airplane is landing. The aerial target having a propulsive propeller, a too elastic train should be taller so that the propeller does not touch the ground when landing, this would lead to a larger train mass. To reduce the mass and elasticity of the train was added carbon fiber structure. Also, in the manufacturing process, it will be necessary to use as little as possible epoxy resin but not to lead to delaminating of the landing gear in time. Table 1 shows the physical properties of epoxy resin. Due to the rapid gelling time and because the manufacturing technology allowed this, the epoxy resin from Table 2 was also used. Table 2 shows the physical properties of the glass fiber used. Table 3 shows the physical properties of the carbon fiber used.

### Table 1. Physical properties of Epiphen 4020 epoxy resin [1], [2]

| Property                  | Value  | MU  |
|---------------------------|--------|-----|
| Elasticity modulus        | 3.5 GPa |     |
| Density                   | 1150 kg/m³ |   |
| Gelling time              | 20÷22 h |     |
| Complete polymerizing time| 14 days |   |
| Breaking resistance       | 54.5 MPa |    |

### Table 2. Physical properties of Resoltech 1050 epoxy resin

| Property                  | Value  | MU  |
|---------------------------|--------|-----|
| Elasticity modulus        | 3.5 GPa |     |
| Density                   | 1140 kg/m³ |   |
| Gelling time              | 130 min. |    |
| Complete polymerizing time| 14 days |   |
| Breaking resistance       | 54.5 MPa |    |
Table 3. Physical property of fiber glass (fiber glass type E)

| Property               | Value   | MU   |
|------------------------|---------|------|
| Elasticity modulus on X| 72      | GPa  |
| Distributed mass       | 500     | g/m² |
| Density                | 2600    | kg/m³|
| Tension on X           | 1.7÷3.5 | GPa  |

Table 4. Physical property of carbon fiber

| Property               | Value   | MU   |
|------------------------|---------|------|
| Elasticity modulus on X| 230     | GPa  |
| Distributed mass       | 160     | g/m² |
| Density                | 1830    | kg/m³|
| Tension on X           | 1.9÷5.6 | GPa  |

5. Model realisation Technology

The realization of the train requires the making of composite material blank and its processing to the final piece. The composite material blank is obtained by applying successive layers of resin-impregnated glass fiber and carbon in a specially designed mold. The mold is inexpensive, easy to make and used, with the possibility of reuse with negligible repairs and costs. The mold has a hot-wire cutting of an extruded polystyrene structure. The mold has two components: the mother mold and the male mold. The mold mat is reinforced in the rolling zone of the composite blank with a layer of resin impregnated glass fiber. The male mold is covered with polyethylene film and scotch adhesive tape. For each use, the mother mold is covered with polyethylene foil fixed and stretched with scotch tape, which is removed after removing the blank from the mold. In the molding process of the blank, the male mold presses the unpolymerized composite from the mother mold by means of distributed weights.
After 24 hours, the composite semi-finished product has polymerized enough to be removed from the mold, cut the required dimension, the surface are polished, the holes in the fuselage and the clamping holes in the tolerances set. The landing train obtained is allowed to fully polymerize for 2 week after which it can be used.

6. Resistances calculus
The maximum stress for the main landing gear is at landing. Thus we considered that sufficient train demand for the overload factor $n=2 \ g$ due to the landing with obstacles and rudimentary arrangements. The landing mass of the airplane is:

$$M = 26 \cdot kg$$  \hspace{1cm} (1)

Under these overload condition, the deformation of the train must allow the propulsion propeller to operate in the main train area. We consider that the impact with the ground is on the two wheels of the train, so the impact force on the wheel will be:

$$F_t = \frac{n \cdot M \cdot g}{2}$$  \hspace{1cm} (2)

The impact friction force will be:

$$F_f = \mu \cdot F_t$$  \hspace{1cm} (3)

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Figure 2: Main landing gear mold. a) Mother mold; b) Male mold; c) Assembled mold. [3]
Figure 3. The forces appearing on the landing gear at ground impact [4]

where: \( \mu = 0.25 \) calculated for an acceleration of -2.4 m/s\(^2\), landing speed 80 km/h and 100 m landing distance

the moments on the three axes are:

\[
M_x = F_i \cdot b1 \\
M_y = F_f \cdot b1 \\
M_z = F_f \cdot h1
\]

(4) (5) (6)

The resistance modules are:

\[
W_x = \frac{bh^3}{3h} \\
W_y = \frac{bh^3}{3h}
\]

(7) (8)

Bending stress will be:

\[
\sigma = \frac{\sqrt{M_x^2 + M_y^2}}{W_x}
\]

(9)

The torque request will be

\[
\tau = \frac{M_x}{W_y}
\]

(10)

According to the resistance theory III, the equivalent stress \( \sigma_{ech} \), will be:

\[
\sigma_{ech} = \sqrt{\sigma^2 + 4 \cdot \tau^2}
\]

(11)
with the components on the two axes:

\[ \sigma_x = \sigma_{ech} \cdot \cos \left( \tan^{-1} \left( \frac{F_i}{F_f} \right) \right) \]  
(12)

\[ \sigma_y = \sigma_{ech} \cdot \sin \left( \tan^{-1} \left( \frac{F_i}{F_f} \right) \right) \]  
(13)

The modulus of elasticity of the fibers can be calculated with formula:

\[ E_f = \frac{S_f E_f n_1 f_s + S_f E_f n_2 f_s \cdot coef + S_{fc} E_{fc} n_1 f_c + S_{fc} E_{fc} n_2 f_c \cdot coef}{S_{fc} n_1 f_s + S_{fc} n_2 f_s \cdot coef + S_{fc} n_1 f_c + S_{fc} n_2 f_c \cdot coef} \]  
(14)

where:
- \( E_f \) – the elasticity modulus of fibers [N/m²]
- \( S_f \) – the mass distributed of fiber glass [g/m²]
- \( E_f \) – the elasticity modulus of fiber glass [N/m²]
- \( n_1 f_s \) – the ply number of fiber glass
- \( n_2 f_s \) – the ply number of fiber glass for stiffening
- \( S_{fc} \) – the mass distributed of carbon fiber [g/m²]
- \( E_{fc} \) – the elasticity modulus of carbon fiber [N/m²]
- \( n_1 f_c \) – the ply number of carbon fiber
- \( n_2 f_c \) – the ply number of carbon fiber for stiffening
- \( coef \) – stiffening ply per ply ratio

The volume of fiber in the composite material is:

\[ V_f = \frac{m_f}{m_f + m_r} \]  
(15)

where:
- \( m_f \) – the total mass of glass fiber and carbon fiber embedded in the composite material
- \( m_r \) – the total mass of resin embedded in the composite material

The modulus of elasticity of the composite material can be calculated using the empirical Halpin-Tisai bonding relations for boron fibers in the aluminum mold, [5]

\[ E_c = E_m \cdot \frac{(E_f + 2E_m)^2 + (E_f - E_m)\cdot V_f}{(E_f + 2E_m)^2 - (E_f - E_m)\cdot V_f} \]  
(16)

where:
- \( E_c \) – composite elasticity modulus
- \( E_m \) – resin elasticity modulus

The transverse elastic modulus \( G \) of the composite material is given by formula, [5]:

\[ G_c = G_m \cdot \frac{(E_f + E_m) + (E_f - E_m)\cdot V_f}{(E_f + E_m) - (E_f - E_m)\cdot V_f} \]  
(17)

where
- \( G_m \) – the resin transverse elastic modulus

Deformations \( \varepsilon \) on the two x,y directions are, [7]:

\[ \varepsilon_x = \frac{\sigma_x}{E_c} \]  
(18)

and

\[ \varepsilon_y = - \frac{\mu \sigma_y}{E_c} \]  
(19)
where:

\[ \mu = -\frac{e_x}{e_y} \]  

(20)

the composite resistance \( R_{cb} \), will be:

\[ R_{cb} = V_f \cdot R_f + \left(1 - V_f\right) \cdot R_m \]  

(21)

where:
- \( R_m \) – resine resistance
- Composite fiber resistance \( R_f \)

\[ R_f = \frac{S_f \cdot R_{f_f} + S \cdot R_{f_c}}{S \cdot R_{f_f} + S \cdot R_{f_c}} \]  

(22)

where: \( R_{f_f} \) – fiber glass resistance
- \( R_{f_c} \) – carbon fiber resistance

Composites resistance deformations \( \varepsilon \), are:

\[ \varepsilon_{rx} = \frac{R_{cb}}{E_c} \]  

(23)

and

\[ \varepsilon_{ry} = -\mu \frac{R_{cb}}{E_c} \]  

(24)

The inertial momentum of landing gear section with variable dimension are:

\[ I_x(x) = \frac{(36\text{mm})^3}{12} \]  

(25)

\[ I_y(x) = \frac{(h^{6h})^3}{12} \]  

(26)

The main inertial momentum are:

\[ I_p(x) = I_y(x) \]  

(27)

Applying the Mohr –Maxwell relation we can calculate train deformation at the wheel. In the two directions \( x, y \) they are, [6]:

\[ \delta_x = \frac{1}{g} \cdot \int_0^{h} \frac{h^{1F_i}x}{I_p(x)} \cdot dx + \frac{1}{E_c} \cdot \int_0^{h} \frac{h^{1F_i}x}{I_y(x)} \cdot dx \]  

(28)

and

\[ \delta_y = \frac{1}{g} \cdot \int_0^{h} \frac{h^{1F_i}x}{I_p(x)} \cdot dx + \frac{1}{E_c} \cdot \int_0^{h} \frac{h^{1F_i}x}{I_x(x)} \cdot dx \]  

(29)

7. Calculation and experimental results

In figure 4 one can see the practical realisation of the mold for obtaining the composite blank. One can identify mother mold, male mold two end feathers, flexible ABS plate and mold clamping frame.
Figure 4. The practical realisation of the matrix to get the composite landing geart

With this mold several composite materials were obtained, resulting in the finishing of landing trains for several unmanned aircraft. On some of the landing trains we measured the displacements on the axis Oy with a mass load of:

\[ M = 19.89 \cdot kg \]  

Table 5. Calculation an experimental results

| No. Crt. | Parameter | Landing gear no. 6 | Landing gear no. 7 | Landing gear no. 8 | Landing gear no. 10 |
|----------|-----------|--------------------|--------------------|--------------------|--------------------|
| 1. | \( F_i \) [N] | 195 | 195 | 195 | 195 |
| 2. | \( F_f \) [N] | 48.7 | 48.7 | 48.7 | 48.7 |
| 3. | \( \sigma_{ech} \) [N/mm\(^2\)] | 39.4 | 39.4 | 39.4 | 39.4 |
| 4. | \( \sigma_x \) [N/mm\(^2\)] | 9.5 | 9.5 | 9.5 | 9.5 |
| 5. | \( \sigma_y \) [N/mm\(^2\)] | 38.2 | 38.2 | 38.2 | 38.2 |
| 6. | \( V_f \) | 0.572 | 0.593 | 0.603 | 0.588 |
| 7. | coef | 1.02 | 0.88 | 0.96 | 0.97 |
| 8. | \( E_{fs} \) [GPa] | 73 | 73 | 73 | 73 |
| 9. | \( E_{fc} \) [GPa] | 230 | 230 | 230 | 230 |
| 10. | \( E_t \) [GPa] | 94.65 | 94.65 | 94.65 | 94.65 |
| 11. | \( E_m \) [GPa] | 3.1 | 3.1 | 3.1 | 3.1 |
| 12. | \( E_c \) [GPa] | 14.52 | 15.43 | 15.95 | 15.19 |
The displacement of the end in condition of load with real aerial vehicle mass:

\[ M = 26 \, \text{kg} \]  

(31)

### Table 6. Theoretical calculus in real loads condition

| No. Crt. | Parameter | Landing gear no. 6 | Landing gear no. 7 | Landing gear no. 8 | Landing gear no.10 |
|----------|-----------|---------------------|--------------------|--------------------|-------------------|
| 1.       | \( F_i \) [N] | 255                 | 255                | 255                | 255               |
| 2.       | \( F_f \) [N] | 63.7                | 63.7               | 63.7               | 63.7              |
| 3.       | \( \varepsilon_x \) | 8.08 \( \times 10^{-4} \) | 8.55 \( \times 10^{-4} \) | 7.82 \( \times 10^{-4} \) | 8.55 \( \times 10^{-4} \) |
| 4.       | \( \varepsilon_y \) | 1.6 \( \times 10^{-3} \) | 1.71 \( \times 10^{-3} \) | 1.56 \( \times 10^{-3} \) | 1.71 \( \times 10^{-3} \) |
| 5.       | \( \varepsilon_{rx} \) | 0.068               | 0.069              | 0.067              | 0.068             |
| 6.       | \( \varepsilon_{ry} \) | 0.068               | 0.069              | 0.067              | 0.068             |
| 7.       | \( \delta x \) [m] | 6.9 \( \times 10^{-4} \) | 7.09 \( \times 10^{-4} \) | 6.03 \( \times 10^{-4} \) | 6.46 \( \times 10^{-4} \) |
| 8.       | \( \delta y \) [m] | 0.024               | 0.025              | 0.023              | 0.025             |

The calculations were made with specific parameters for each landing train, especially \( h \), \( b \) and their variation per unit of length. Also, \( V_f \) specific to each landing train were calculated based on the experimental data recorded in the manufacture of these train. We have noticed that a major influence on the calculated displacement \( \delta_y \), is the measured \( h \) thickness of the train at embedding. The trains have been designed to reduce weight without affecting the strength and stiffness of the tread. For this, the thickness \( h \) was reduced by reducing the fiberglass layers and adding carbon fiber layers to the stiffness and further reducing, as much as the manual overlay technology of the composite layers, the amount of resin in the composite. Thus, the train do not have a regular shape in the fuselage area and therefore the measurement
of the h parameter is affected by errors that have a great influence on the obtained results. For example, the 0.1 mm increment of the measured thickness h changes the displacement $\delta_y$ by 1÷2 mm. The deformations obtained do not exceed the resistances deformations of composite, presenting safety in operation.

8. Conclusions
The rigorous control of landing gear parameter in the design made it possible to reduce the landing gear mass approximately 260 g from about 1050 g to about 790 g while maintaining the maximum aircraft weight and using a briefly arranged landing. Also affordable and reliable cheap manufacturing technology has made it possible to get the main landing gear at low cost. The timing of train is about 2.5 hours, including mold preparation time and material cutting.

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