MANUFACTURING OF A LANDING GEAR USING COMPOSITE MATERIALS FOR AN AERIAL TARGET

Ionuț Ciobanu*, Liviu Drăguș*, Laura Țigleanu*, Cătălin Frunză*, Dan Bălăuță* and Șerban Olaru*

* Military Equipment and Technologies Research Agency, Bucharest, Romania

Abstract
In this paper we are presenting a manufacturing method for a main landing gear of an aerial target. We approached the stages of manufacturing of a main landing gear from composite materials dedicated for an aerial targeted plane. In the first stage we designed a reduced mass landing gear by using CAD/CAM simulation and design (Solids Works). In the second stage we realised the manufacturing technology to create the CAD model at a reduced cost. For this, we designed and manufactured the mould of composite preform and the mathematic model where we configured the mass and dimensional parameters for the main landing gear. We verified this mathematical model by comparing the mass and dimensional parameters theoretically obtained with the practical ones for more manufactured landing gears.

Key words: manufacturing, landing gear, aerial target, composite materials

1. Introduction

The composite materials are more and more used for aircraft structure components, due to their higher rigidity and stiffness compared to aluminium and steel. Reducing mass, by using composite materials, was one of the main targets for applying these materials. Today, a reduced cost of a preform becomes more important. The main target is to combine new efficient manufacturing methods with structural low mass concepts, therefore the study of the materials to advance to a higher level.

The landing gear is the main subassembly that is mostly stressed during take off, landing and standing still. During landing, the landing gear is designed to absorb the impact energy of landing so as the transferred payloads on the aircraft’s body to be reduced to a minimum.

The need of increasing aircraft performance by using low mass procedures has changed the research nowadays from conventional advanced metallic materials such as aluminium and steel alloys, to composite materials. The high stiffness and rigidity of the composite materials, corroborated with their economic feasibility, are the keys for aircrafts manufacturing. When the aircraft is landing smoothly, the maximum capacity of energy is to be absorbed by the main landing gear which is suffering a big stress. This procedure needs a nonlinear analysis using CAD/CAM methods in order to predict its mechanical behaviour, before manufacturing and design. The energy absorbed by the main landing gear is stored as a versatile energy, therefore the material used for manufacturing this component must have a high capacity of storing the versatile tensions. The main goals for a main landing gear are: high mechanical stiffness, low weight, medium rigidity and high capacity of storing energy tensions.

The goals in aviation when using composite materials for manufacturing landing gears were:

- increasing aircraft’s performance and ruggedness, by reducing the mass up to 30%.
- excluding corrosion and cracks.

This study proposes to analyse the behaviour of a landing gear made from composite materials, used on an experimental radio controlled target plane TD (target drone), in static and dynamic loads. The integrity of the landing gear is studied regarding the stiffness of the main aircraft weight and the dynamic impact of the aircraft. The results obtained like stress distribution in composite
materials, the yieldings and the imperfection detection will be determined in order to evaluate the
critical zones of the landing gear. The results must be within the brake stress limits of the material.

2. The design of the landing gear

The composite material of the landing gear has certain limitations regarding its mass,
elasticity, surface roughness, dimensions and stress durability.

A. The geometry of the landing gear

Figure no.1 presents the CAD model of the main landing gear designed for a radiocontrolled
targeted aircraft preform. Some of the assembling parts such as wheels, screw bolts, axes and bolt nuts,
were ignored for simplifying the model.

The geometric characteristics of the preform landing gear are the following, figure 1:
- Height: 320 mm
- Length: 650 mm
- Width: variable from 45 mm at ends to 80 mm in the central zone
- Thickness: variable from 5 mm at ends to 9 mm in the central zone
- The hole diameter attached on the body: 6.2 mm
- The hole diameter attached on the wheels: 10.2 mm

![Figure 1. The geometric characteristics of the preform landing gear](image)

B. Type of material

The main landing gear is a composite material made of glass fiber, carbon fiber and epoxy
resine. The quantity of glass/carbon fiber has been chosen having the following characteristics: the
glass fiber assures flexibility and the carbon fiber assures rigidity. In the manufacturing processes
there will be used a small amount of epoxy resin so as the landing gear does not delaminate in time;
therefore the proportion of the fiber/resine must be approximately 55/45 at 100 percent. In table 1 are
presented the physical properties of the composite material that were used [2].

| Properties                     | Value | Unit |
|--------------------------------|-------|------|
| Flexibility module on X        | 250   | GPa  |
| Poisson coefficient module on XY | 0.27 | -    |
| Rigidity module on XY          | 5.8   | GPa  |
| Density                        | 1830  | kg/m³|
| Tensile stress on X            | 650   | MPa  |
| Properties                  | Value | Unit |
|-----------------------------|-------|------|
| Compression stress on X     | 600   | MPa  |

C. Finite element discreditation

Figure 2 presents the main landing gear meshed by pyramidal type finite element. In order to obtain precise results there has been designed a smooth transition near the holes assembling areas. In this processes there was created a number of 17316 elements with 30725 mesh points.

![Figure 2. The main landing gear](image)

D. Limits and payloads conditions

The landing gear of the target plane consists of a three axes cycle, consisting of the main landing gear (which is studied in this paper) and the one wheeled front axle of the plane. The main landing gear of the plane takes the first shock during landing, figure 3. The behavioural analysis of the main landing gear must take into account the worst conditions which can take place in the landing process such as:

- Natural track: with subsidences and holes, grassy surface;
- Weather conditions: normal weather to severe;
- The mass of the plane does not exceed 30kg.

Taking care of these flight performances of the plane and the weather conditions in which the plane runs smoothly, we will analyse the behaviour of the main landing gear for a payload of 3g with 3 hypothesis for impact of the landing gear with the ground, for the following payloads: 300N (overcharge 1g), 600N (overcharge 2g) and 900N (overcharge 3g).

![Figure 3. Limit conditions and payloads](image)
E. Results and analysis

The main landing gear made of composite materials, designed with the finite element method, was analysed and measured to determine the stress produced at the impact with the ground.

![Figure 4](image)

**Figure 4.** Distribution of the tensions von misses and displacements for a 300N payload (overcharge 1g)

![Figure 5](image)

**Figure 5.** Distribution of von misses tensions and displacements for a 600N payload (overcharge 2g)

![Figure 6](image)

**Figure 6.** Distribution of von misses tensions and displacements for a 900N payload (overcharge 3g)

From the distribution of the von misses in figures 4, 5, 6 we may realise the following:

- The maximum stress is in the upper part of the wheel’s axis hole of the landing gear, the value increasing from 50 Mpa for 1g overload to 149 Mpa for 3g overload.
- The central area of the landing gear is medium stressed about half of the maximum stress value of the hole upper part of the assembly of the wheel axis of the main landing gear.
- The curved zone of the main landing gear is less stressed.
The design of the main landing gear was designed for a low mass weight without affecting its strength. According to these facts we respect the following:

- The curved shape of the landing gear allows it to overtake the stress steadily, with no fractures and brake points on the part.
- Considering that the low level of stress is on the high end of the landing gear, near the wheel assembly area, we decided to reduce the thickness and the width all along the boundary of the landing gear, thus reducing considerably the mass weight.

From the von misses analysis distribution of the tensions and from the displacement distribution we can conclude that the structure is safe for the given payloads.

3. Mathematical model

From the start we have to calculate the total mass of the preform and its thickness by counting the number of glass fiber and carbon layers and the total mass resin weight to be used for preform. Total mass glass fiber sheets

\[ M_s = S_p \cdot S_s \quad (1) \]

Total mass carbon fiber sheets

\[ M_c = S_p \cdot S_c \quad (2) \]

where:

- \( S_p \) - sheet surface \([m^2]\]
- \( S_s \) - glass fiber density \([g/m^2]\]
- \( S_c \) - carbon fiber density \([g/m^2]\]
- \( M_s \) - glass fiber sheet mass \([g]\]
- \( M_c \) - carbon fiber sheet mass \([g]\)

The total mass fiber used is:

\[ M_{fs} = M_s \cdot cs1 + 0.8 \cdot M_s \cdot cs2 \quad (3) \]

\[ M_{fc} = M_c \cdot cc1 + 0.8 \cdot M_c \cdot cc2 \quad (4) \]

\[ M_{ps} = 0.8 \cdot M_s \quad (5) \]

\[ M_{pc} = 0.8 \cdot M_c \quad (6) \]

\[ M_f = M_{fs} + M_{fc} \quad (7) \]

where:

- \( M_f \) - total mass carbon and glass fiber \([g]\)
- \( M_{fs} \) - total glass fiber mass \([g]\)
- \( M_{fc} \) - total carbon fiber mass \([g]\)
- \( M_{ps} \) - glass fiber rigidity mass sheet \([g]\)
- \( M_{pc} \) - carbon fiber rigidity mass sheet \([g]\)
- \( cs1 \) - number of layers glass fiber full sheet
- \( cs2 \) - number of layers rigidity glass fiber sheet
- \( cc1 \) - number of layers carbon fiber full sheet
- \( cc2 \) - number of layers carbon fiber rigidity sheet
- 0.8 - coefficient representing the procentual mass from the procentual whole mass sheet

We are obtaining the resin coefficient used for preform considering that the carbon fiber and glass fiber layers are laminated with the same amount of resin, as following:

\[ m_r = M_{fs} \cdot co + M_{fc} \cdot co \quad (8) \]

where:

- \( m_r \) - total resin mass \([g]\)
- \( co \) - resin coefficient used

The percentage of resin from the layer to be laminated, \( r_p \), is [1]:

\[ r_p = \frac{M_{fs} \cdot co}{M_{fs} \cdot co + M_{fs}} \times 100 \quad (9) \]

The thickness of the layer to be laminated will be calculated with [1]:

- For glass fiber
\[ Gr1 = cco \cdot \frac{100 - rp}{rp} \cdot \frac{Sc}{\rho r} \]  
(10)

For carbon fiber

\[ Gr2 = cco \cdot \frac{100 - rp}{rp} \cdot \frac{Sc}{\rho r} \]  
(11)

where:

- \( Gr1 \) - the thickness of laminated layer from the glass fiber [m]
- \( Gr2 \) - the thickness of laminated layer from the carbon fiber [m]
- \( \rho r \) - resin density [g/cm³]
- \( cco \) - the contraction coefficient of laminate

The train width in the maximum load area, \( Gmax \), is:

\[ Gmax = cs1 \cdot Gr1 + cs2 \cdot Gr1 + cc1 \cdot Gr2 + cc2 \cdot Gr2 \]  
(12)

Train thickness in the wheel mounted zone:

\[ Gmax = cs1 \cdot Gr1 + cc1 \cdot Gr2 \]  
(13)

4. The manufacturing process of the main landing gear

The mold required to manufacture the main landing gear was executed of two parts, the female part in which glass fiber / carbon fiber is laminated with epoxy resin, and the male part in order to press the composite material. It has been chosen for the extruded polystyrene mold to be executed due to ease of hot wire cutting. To increase rigidity, the mold was reinforced with glass fiber layers and epoxy resin, figure 7.

The stages of the technological process for obtaining the landing gear from composite material are as follows:
I. Prepare the mold elements: cover the mold structure with polyethylene foil and adhesive scotch tape so that it does not come into contact with the resin;

II. Prepare the glass / carbon fiber layers: remove the glass / carbon fiber sheets aligned on the fiber strip with a laser cutting machine. The triangular shape remains and the end strips after cutting will be used as rigidity sheets;

III. Based on experience, the percentage of resin and fiber in the laminate layer is determined;

IV. The number of laminate layers are determined and the mass and train thickness are theoretically calculated whether they correspond to the designed and calculated train at mechanical stresses. Set the number of fiber layers and quantity of resin required and proceed to the next step, if not, return to step III.

V. Weigh out the total fiber to be used in order to fabricate the train and added with theoretically determined quantity of resin, should be equal to 1.05x (train mass + mass of processing charge); (1.05 is a coefficient representing the volume contraction of the epoxy composite material + fiber);

VI. Prepare some of the quantity of resin so that it remains fluid at working temperature without gelling until it is consumed;

VII. Apply with a brush a first resin layer on the surface of the mold. The resin layer should be thick but not flowing.

VIII. Apply the first fiber layer (glass or carbon) and impregnate the fiber with a brush by buffering. If it is necessary, apply small quantity of resin until the fiber is fully impregnated. It is necessary a good impregnation of first layer so that the outer surface obtained after the complete polymerization is smooth and glossy.

IX. Apply the next fiber layer. If the fiber has a density 160 g / cm² approximately, it is buffed with the brush over the entire surface, after which a very thin resin layer is applied by brushing a small quantity of resin (taken from the resin container on top of the brush).

If the fiber has a density 500 g / cm², approximately the fiber is buffered into the center area of the mold and brushed on fiber surface by vigorously pressing to impregnate with the previous layer resin. Apply with brush small quantities of resin on both sides at an equal distance of the same line away from the long edges of the fiber, starting with the center of the mold and descending successively to its base, respectively, on the left and right side.

X. Apply successively all fiber layers and each will be impregnated with resin after the IX procedure.

XI. The last layer will be applied according to IX procedure.

XII. After the last layer, there should remain approximately 27 g of resin to impregnate the interstices between the mold and the edges of the deposited fiber layers and a generous impregnation of the last fiber layer. If we do not have resin for impregnation, prepare an additional 27 g, approximately and apply it. If we consider that it still needs to be impregnated, after applying this quantity, we prepare and apply as needed.

It should be taken into account that the prepared ABS foil which is in contact with the composite around the contact area provides a smooth and glossy polymeric surface area. In the center of the mold where the ABS foil does not come into contact with the composite, the surface will have the appearance of application after polymerization.

XIII. Over the unpolymerised composite, pre-prepared ABS foil is applied. Above the ABS foil is applied the semi-mold cover and two pressing wedges are inserted between them. The mold is caught in the pressing frame over which weights are placed (about 20 kg). Finally, tighten the clamping screw of the pressing frame until the composite resin begins to flow. If the resin added to the last layer is additional, we tighten harder until a small amount of resin has been poured.

XIV. Allow the preform to polymerize for 24 hours and then remove it from the mold;

XV. Remove the bumps and polish the sharp edges;

XVI. The preform is debited to the required size

XVII. Drill in the preform the holes for attaching the wheels and the for attaching the fuselage.

5. Validating mathematical mode

Sheet parameters are presented in table 2:
Table 2. Sheet parameters used

| Parameter               | Glass fiber | Carbon fiber | Glass fiber | Glass fiber |
|-------------------------|-------------|--------------|-------------|-------------|
| Train number            | 1-10        | 11           |             |             |
| Density                 | 500 g/m²    | 160 g/m²     | 300 g/m²    | 160 g/m²    |
| Full sheet surface (Sp) | 0.0734025 m²|              |             |             |
| Rigid sheet surface (Sp)| 0.8 x 0.0734025 m² | 0.8 x 0.0734025 m² | -            |             |

Resin parameters are presented in table 3:

Table 3. Resin parameters used

| Type        | Epiphen 4020 |
|-------------|--------------|
| Density (ρr) | 1.04 g/cm³   |

Preform parameters are presented in table 4:

Table 4. Composite preform parameters

| Train number | Layer type | Glass fiber resin (500 g/m²) | Carbon fiber resin | Glass fiber resin (300 g/m²) | Glass fiber resin (160 g/m²) |
|--------------|------------|------------------------------|--------------------|------------------------------|-------------------------------|
| 1-10         |            | cs1 = 8                      | cc1 = 4            | cs2 = 4                      | cc2 = 2                       |
| 11           |            |                              |                    |                              |                               |

Note: ** The fiber layers are full sheet

Experimental results and calculations are presented in table 5

Table 5. Experimental and theoretical results

| Train number | Quantity of fiber before casting (g) | Calculated 8-11 / measured 1-7 | Preform mass (g) | Theoretical mass (g)- calculated | Composite contraction (co) - calculated | Thickness mm |
|--------------|--------------------------------------|---------------------------------|------------------|----------------------------------|------------------------------------------|--------------|
|              |                                      |                                 |                  |                                  |                                           | Maximum composite | Minimum composite |
| 11           | 547                                  | 440                             | -                | 928                              | 987                                      | 876          | 11.1  | 8.54  |
| 10           | 506                                  | 355                             | -                | 827                              | 861                                      | 775          | 9.2   | 9.05  |
| 9            | 506                                  | 375                             | -                | 844                              | 881                                      | 792          | 9.6   | 8.65  |
| 8            | 506                                  | 376                             | -                | 845                              | 882                                      | 776          | 9.9   | 8.63  |
| 7            | 490                                  | 336                             | 0                | 814                              | 826                                      | 806          | 10.1  | 9.61  |
| 6            | 514                                  | 384                             | 7                | 845                              | 891                                      | 779          | 9.5   | 8.65  |

Note: ** The fiber layers are full sheet

Experimental results and calculations are presented in table 5
Train number & Quantity of fiber before casting (g) & Measured 8-11 & Calculated 1-7 & Quantity of casted resin (g) & Measured 1-7 & Calculated 8-11 & Preform mass (g) & Theoretical mass (g) & Calculated & Final mass (g) & Composite contraction (\%)-calculated \hline
5 & 500 & 383 & 0 & 828 & 883 & 776 & 0.94 & 10.7 & 8.19 & 7 & 5.46
4 & 500 & 385 & 7 & 841 & 878 & 783 & 0.96 & 10.7 & 8.47 & 7.8 & 5.65
3 & 498 & 379 & 8 & 843 & 869 & 791 & 0.97 & 7.9 & 8.71 & 7 & 5.8
2 & 503 & 382 & 7 & 845 & 878 & 765 & 0.96 & 8.5 & 8.63 & 8.2 & 5.75
1 & 491 & 390 & 6 & 816 & 871 & 769 & 0.94 & 9 & 7.89 & 8.4 & 5.4
Medium values & 506 & 380 & 6 & 843 & 882 & 790 & 0.96 & 9.95 & 8.64 & 6.96 & 6.03
\hline

Note: 1 To execution trains number 8-11, the values of the quantities of fiber and resin used, were not accurately recorded
Fiber quantity before casting – the total mass of glass and carbon fiber is measured
Quantity of cast resin - represents the value of the total mass of the used resin obtained by summing partial quantities of resin prepared and deposited on the layers
Quantity of drained resin - represents the value of the total mass of the resin drained from the mold on the work table
Preform mass - represents preform mass removed from the mold
Theoretical mass - represents mass of resin and fiber used
Final mass- represents the train’s mass after cutting and finishing
The average error of composite thickness resulted, compared to the calculated thickness is 15% approximately for both stress area and wheel attachment area. The maximum error due to the manufacturing technology for the final train mass is 5% and 43% for thickness.
Differences between the half-finished train thickness values may be due to manufacturing defects that result after air inclusions in the half-finished train.
Regarding the values of minimum thickness area, the mold does not press the half-finished train, and air inclusions can make the difference.
Another minimal thickness area with the same laminates layers is the area where the train wheels are attached, where the mold presses on uncured half-finished train, therefore the resin flows out of the composite. In this area the measured and calculated values are as follows, table 6:

Table 6. Minimum thicknesses measured and calculated on the landing gear

| Train number | Thickness (mm) | Left Pressed-Composite | Right Pressed-Composite | Minimum composite-calculated |
|--------------|----------------|------------------------|------------------------|----------------------------|
| 11           | 5.3            | 5.8                    | 8.54                   |
| 10           | 5.6            | 8.6                    | 6.03                   |
| 9            | 5.5            | 7.5                    | 5.76                   |
| 8            | 4.6            | 7.1                    | 5.75                   |
| 7            | 5.1            | 6                      | 6.41                   |
| 6            | 5              | 7                      | 5.76                   |
| Train number | Thickness (mm) |  |
|--------------|----------------|-----|
|              | Left Pressed-Composite | Right Pressed-Composite | Minimum composite-calculated |
| 5            | 5.1             | 6   | 5.46  |
| 4            | 4.8             | 6.5  | 5.65  |
| 3            | 5               | 6.8  | 5.8   |
| 2            | 5.5             | 7.1  | 5.75  |
| 1            | 5.7             | 7.5  | 5.4   |
| Medium values-calculated | 5.17           | 6.71 | 6.03  |

6. Conclusions

From the finite element analysis it can be concluded that the landing gear is safe for the given loads. Mathematical modeling of the mass and thickness for the composite preform made it possible with 15% approximately error of the theoretical model. Maximum error due to manufacturing technology for the final landing gear is 5% for mass and 43% for thickness. We consider that the important parameter is the landing gear mass, because landing gear thickness variation insignificantly affects airspeed performance for low subsonic speeds. The manufacture costs of the landing gear are reduced due to using a mold that is affordable and made of accessible materials, allowing the manufacturing of more than 20 landing gears and the mold is still usable.

7. References

[1] Composite materials, course notes, Faculty of Aerospace Engineering, 1998-1999, Bucharest, Romania
[2] Solids Works 2017, materials property