# Application of polymeric-composite materials in the construction of nacelle and tail beam of pseudo satellite

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**Abstract.** The issues of using modern polymer-composite materials in creating a pseudo-satellite are considered. In particular, attention is focused on the design of nacelle frames and tail booms as spatial elements, the mechanics of which are still insufficiently substantiated. The challenge of providing reliable connections in the tubular structure of the truss tail boom with strict requirements for mass and overloads in flight has led to the use of a method wrapping the ends of carbon tubes with aramid thread using epoxy resins. This connection can provide adequate strength in terms of the variables in sign and absolute value of the loads with minimal increase in the weight of the overall product. The practical results of the work and calculation data are given, on the basis of which specific designs of the nacelle and the tail boom of the pseudosatellite are realized. Manufactured and applied these connections ensure the minimum weight and maximum breaking force of the structure and, accordingly, are suitable for use in the manufacture of a pseudo-satellite.

## 1. Introduction

The need to develop structures made of polymer-composite materials arises due to the very small specific load per unit area of the pseudo-satellitewing (≈3kg/m$^2$), the wingspan of more than 11m, length of about 5 m and the calculated maximum overload $n_y = 7$ [1].

In particular, during design it was established that the mass of the tail beam of the aircraft should be within 1.4 kg at a length of 3.3 m. In this case, in the clamping of the beam near the wing there are longitudinal forces that causethe rods to stretch, with a value of 100…150 kGf. Accordingly, there is a contradiction between the requirements for strength and weight. The solution to this contradiction is possible under the condition of using polymer composites with a certain organized structure. According to the known data on typical construction materials, the most suitable for this role is carbon fiber in the tubular form, which forms a direction-oriented structure capable of withstanding a tensile force up to 55 kGf/mm$^2$ and having a density of about 1.5g/cm$^3$.

Due to the fact that in the market of polymer composites the required finished products are almost absent, and most of their components are sold, it was decided to develop and manufacture structural elements of the aircraft, including the tail beam of semi-finished products in the form of carbon tube and aramid threads.

## 2. Materials

As the first component of the structural composite material, we chose Tenax®-J HTA40 carbon fiber, the characteristics of which are shown in the table. 1 [2].

**Table 1.**Characteristics of carbon fiber "Tenax®-J HTA40".

| Productionsite | Fiberfamily&tensile properties | Sizingproperties | Numberoffilaments | Nominallineardensity (withoutsizing) | Additional information | Tensile strength [MPa] | Tensile modulus [GPa] | Elongation at break [%] | Filament diameter [µm] | Density [g/cm³] | Sizing Size level [%] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TenaxJHTA40 | E15 | 1K | 67tex | 15S | 4100 | 240 | 1.7 | 7.0 | 1.77 | EP | 2.5 |

As a binder (glue) was chosen epoxy resin SR1700 with hardener SD7820 and the following characteristics (table 2) [3].

**Table 2.** Some characteristics of epoxy resin SR 1700 with hardener SD7820.

| № | Parameter | Value |
|---|---|---|
| 1 | Reactivity | Slow approval |
| 2 | Resin color | Yellow |
| 3 | Viscosity, mPa.s | 120 at 15°C |
| 4 | Density, g / $cm^3$ | 0,96 |

## 3. Methods and Results

*3.1. Development and manufacture of braces and rods of the stress fuselage set of the aircraft and their termination.* Tubular struts and rods distribute the bending and torsional loads that are perceived by the concentrated/distributed masses during the action of the corresponding overloads on the design of the pseudo-satellite. Braces and thrusts are widely used in particular in the design of the pseudo-satellite nacelle. The frame of the nacelle with the corresponding rods and braces is shown in figure 1.

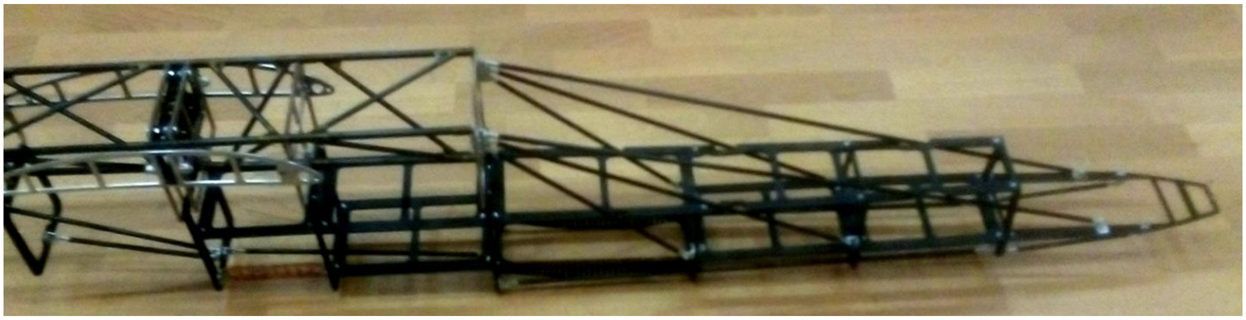

**Figure 1.** Gondola frame with appropriate braces and rods

The design of a typical braces (rods) of the pseudo-satellite is given in figure 2.

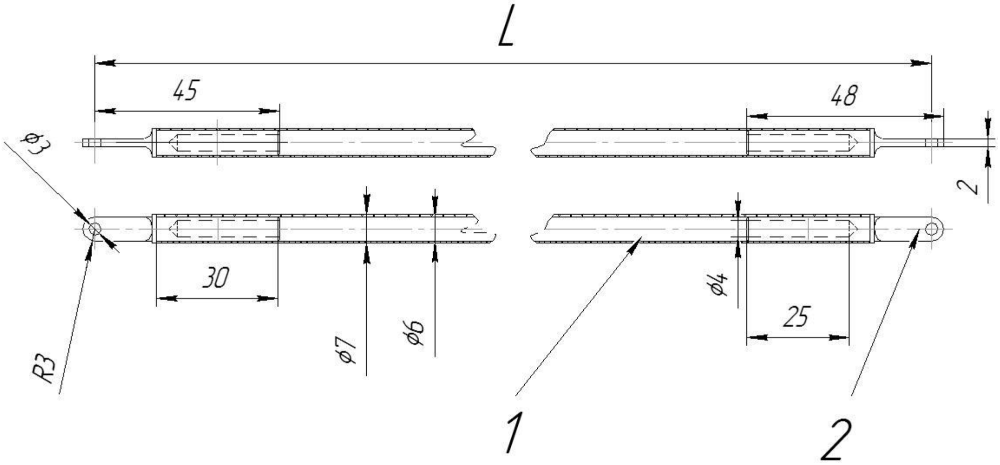

**Figure 2.** The main components, sizes and dimensions are typicalbraces and rods

The basis of the thrust is a carbon (carbon fiber) tube 1 with an outer diameter of 7 mm and an inner diameter of 6 mm. At the ends of the tube are fixed tips 2, which are made of material D16T. The dimension L ranges from 195 mm to 842 mm.

*3.2. Break-critical areas of typical braces and rods.*

**Plot number 1.**

According to passport data, carbon fiber tubes (when winding layers at an angle of $45^0$) have a tensile strength $\sigma_p$=55-60 kGf/mm$^2$ [4]. The cross section of the tube measuring 7mm x 6mm is Sc.s. = 10.2 mm$^2$. Accordingly, the breaking force of the tube will be equal to:

$$F_{b.f} = \sigma_p \text{ x } S_{c.s.} = 60 \text{ x } 10{,}2 = 612 \text{ kGf.}$$

**Plot number 2.**

Another critical place where the destruction of the material (rupture) can also occur is the eyelet of the tip in figure 3.

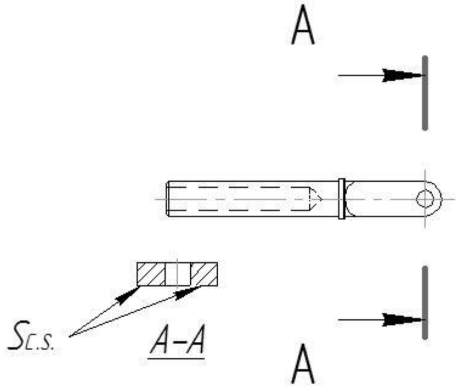

**Figure 3.** Critical cross section of the eyelet of the tip

The specified cross section is estimated by the cross-sectional area $S_{c.s.,}$ which is numerically equal to $S_{c.s.}$= 6mm$^2$. The eyelet is made of DI6T material, in which the specific tensile load is in the range $\sigma_{rD16T}$ = 39-40 kGf /mm$^2$ [5].

Accordingly, the breaking force for the eyelet will be equal to:

$$F_{b.f.e} = \sigma_{rD16T} \text{ x } S_{c.s.} = 40 \text{ x } 6 = 240 \text{ kGf.}$$

However, in the process of pulling the hole, the eyelets with a diameter of 3 mm may lose their configuration, ie the shape of the hole may change from round to semi-elliptical. This occurs when during the stretching of the material D16T the stress $\sigma_{rD16T}$ = 32 kGf/mm$^2$ is reached and the material begins to elongate (the yield strength is reached). Accordingly, the force at which the shape of the holewillbegin to deform is equal to:

$$F_{b.f.e.s} = \sigma_{rD16T.st} \text{ x } S_{c.s.} = 32 \text{ x } 6 = 192 \text{ kGf.}$$

**Plot number 3.** The most critical area where damage can occur is the connection between the two parts, namely the tip and the carbon tube. The connection is made using Sicomin SR7100 epoxy resin on the K surface in figure4.

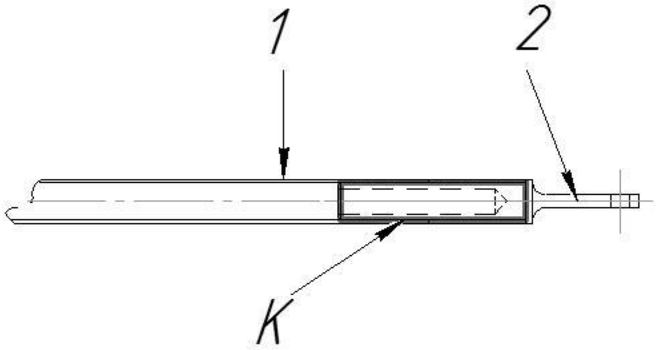

**Figure 4.** Elements of the glued connection of the tip and the carbon tube: 1 - carbon tube 7x6 mm; 2 - tip (D16T); K - epoxy adhesive application surface

To obtain the strength of this joint, the bonding area$S_K$ = 546 mm$^2$ was calculated. Bonding was performed with Sicomin SR7100 resin as part of Sicomin SR7105 hardener [6]. According to the passport data, the specified resin has the following physical and mechanical properties shown in table 3:

**Table 3.** Some physical and mechanical properties of Sicomin SR7100 resin [7].

| Duration and temperaturepasting | 7 days<br>at 23 ° C | 16 hours<br>at 40 ° C | 8 hours<br>at 60 ° C |
|---|---|---|---|

| | | | |
|---|---|---|---|
| The nature of the load (shift) | - | - | - |
| Maximum resistance N/mm$^2$ (kgf/ mm$^2$) | 32 (3,26) | 31 (3,16) | 35 (3,57) |

Given the applied heat treatment condition of the specified connection (8 hours at 60°C), in the calculation of the destructive shear stress is assumed as $\tau_{7100} = 3.57$ kGf / mm$^2$.

Accordingly, the maximum force at which the destruction of the glued connection of the carbon tube and the tip is equal to:

$$F_t = \tau_{7100}\ \mathrm{x}\ S_K = 3{,}57\ \mathrm{x}\ 546 = 1950\ \mathrm{kGf.}$$

Due to the nature of the loads, the rods and traction are mainly subject to tensile loads. Accordingly, the critical cross sections of a typical thrust (brace) are the areas shown infigure5.

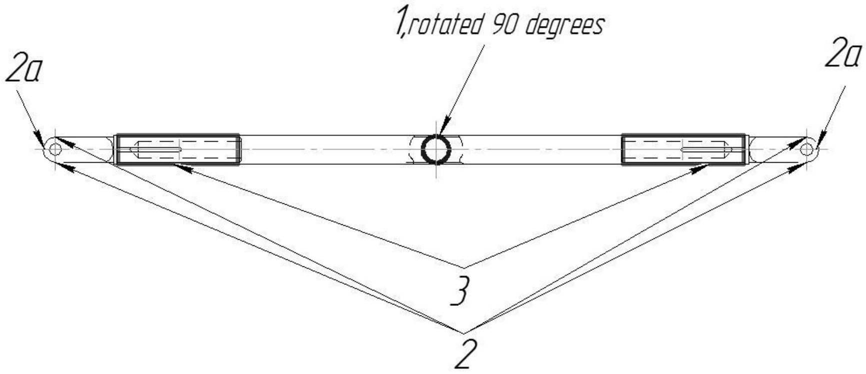

**Figure 5.** Location of critical cross sections regarding the possible destruction (rupture) of the typical thrust (brace) of the pseudo-satellite:

1 – cross section of a carbon tube of 7 x 6 mm;

2 - cross sections of the eyelets of the tips;

2a is the probable place of drawing a round hole and reducing its cross-sectional area (longitudinal section);

3 - bonding surface of the carbon tube and tip.

The results of the calculation are summarized in the final table 4.

**Table 4.** Final table of results of calculations of strength (tensile) of critical cross sections of typical thrust (brace).

| № | Section (surface) name | Destructive tensile force kGf (kN) | Bonding strength rating |
|---|---|---|---|
| 1 | Carbon tube diam. 7 mm x diam. 6 mm | 612 (5,9976) | 2 |
| 2 | The cross section of the eyelet of the tip (1.5 mm x 2 mm) x 2 | 240 (2,352) | 3 |
| 2a | Longitudinal section of the eyelet of the tip (1.5 mm x 2mm) | 192 (1,881) | 4 |
| 3 | Bonding surface of carbon tube and tip ($S_K$ = 546 mm$^2$) | 1950 (19,110) | 1 |

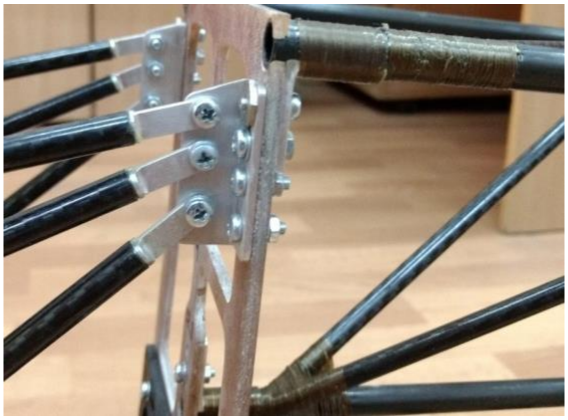

**Figure 6.** The image of nacelle bracket attachement to a frame

***Making connections for tail beam rods and connecting their fragments.***

In the process of manufacturing the tail boom (hereinafter referred to as HB), it was necessary to ensure the connection of the link sections with the corresponding strength characteristics. The connection had to be one-piece, technologically advanced, lightweight and with a minimum number of parts. According to the adopted technical solutions, the following type of mechanical connection was determined as shown in figure7.

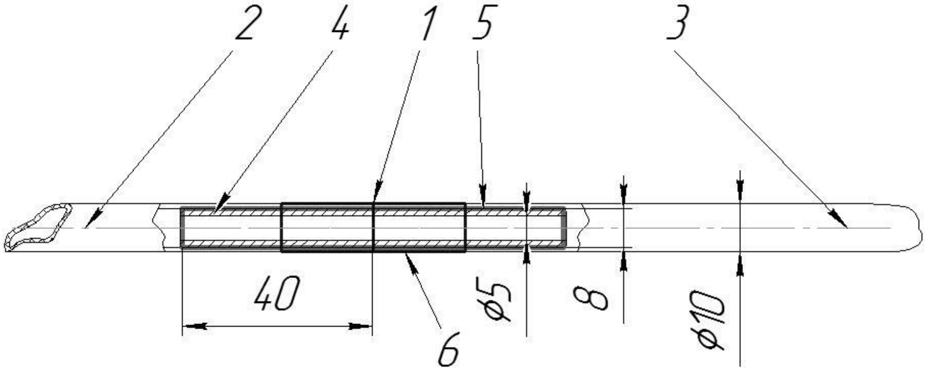

**Figure 7.** General view and dimensions of the connection of the sections of the rods of the tail beam of the pseudo-satellite:

1 - line of connection of sections (tubes) of the tail beam rods;
2 - the first section of the rod;
3 - the second section of the rod;
4 - connecting coupling;
5 - gluing surface of carbon tubes - sections and couplings;
6 - the surface of the winding of the edges of the sections with aramid thread.

As seen from figure7, the connection is based on a tubular sleeve that fits snugly into the tubing sections of the rods ofthe tail beam. The sections and the coupling are connected with each other using Sicomin SR7100 epoxy glue as part of the Sicomin SR7105 hardener. In addition, to prevent the destruction of carbon fiber from the ends, a force (with an interference) winding of the edges of carbon tubes with aramid thread is used.

To ensure the appropriate strength of the the tail beam rods, it is necessary to obtain the strength of this glued joint not less than the strength of the body (section) of the carbon fiber tube, in particular, the following inequality must be true:

$$F_{d.f.g} \geq F_{d.f.c}$$

where:

$F_{d.f.g}$- destructive force for the glued joint;
$F_{d.f.c}$- destructive force for the cross section of a carbon fiber tube.

Tensile is considered to be the main type of load, as the three-rod tail beam is considered to be clamped cantilevered in the centerplane of the pseudo-satellite wing; its loads are due to aerodynamic forces acting on the vertical and horizontal tail.

According to the passport data, carbon fiber tubes (when winding the layers at an angle of $45^0$) have a tensile strength $\sigma_{b.carb.}$=55-60 kGf/mm$^2$. The cross section of the tube measuring 10 mm x 8 mm is $S_{c.s}$ = 28.3mm$^2$. Accordingly, the breaking force of the tube will be equal to:

$$F_{b.f.s.} = \sigma_{b.carb.} \text{ x } S_{c.s.} = 60 \text{ x } 28{,}3 = 1698 \text{ kGf.}$$

The coupling is made of carbon fiber (8 mm x 5 mm) and has a cross section of $S_{c.s.}$ = 30.6 mm$^2$.

Accordingly, the breaking force of the coupling will be equal to:

$$F_{b.coup.} = \sigma_{b.carb.} \text{ x } S_{c.s.} = 60 \text{ x } 30{,}6 = 1836 \text{ kGf.}$$

The seam to be glued is made with Sicomin SR7100 epoxy glue mixed with Sicomin SR7105 hardener. For this type of joint and tensile load, the adhesive bond is evaluated by the parameter "shear strength". The corresponding passport data of the glue are given in Table 3. The area of the glued surface of one area and ½ of the coupling is $S_{s.g.}$=1000.5 mm$^2$. Obviously, the following efforts are required to destroy the adhesive seam in this section of the joint:

$$F_{d.s.g.} = \tau_{7100} \text{ x } S_{s.g..} = 3{,}57 \text{ x } 1000{,}5 = 3588{,}6 \text{ kGf.}$$

The results of the calculation are summarized in the final table 5.

**Table 5.**Final table of results of calculations of strength (tensile) of critical sections of glued connection of the rods the tail beam.

| № | Section (surface) name | Destructive tensile force kGf (kN) | Bonding strength rating |
|---|---|---|---|
| 1 | Carbon tube (section) 10 mm x 8 mm | 1698 (16,640) | 3 |
| 2 | Cross section of the coupling (8 mm x 5 mm) | 1836 (17,992) | 2 |
| 3 | Bonding surface of carbon tube and ½ coupling | 3588,6 (35,168) | 1 |

In figure 8 shows an example of the use of a coupling connection in the design of the tail beam rod.

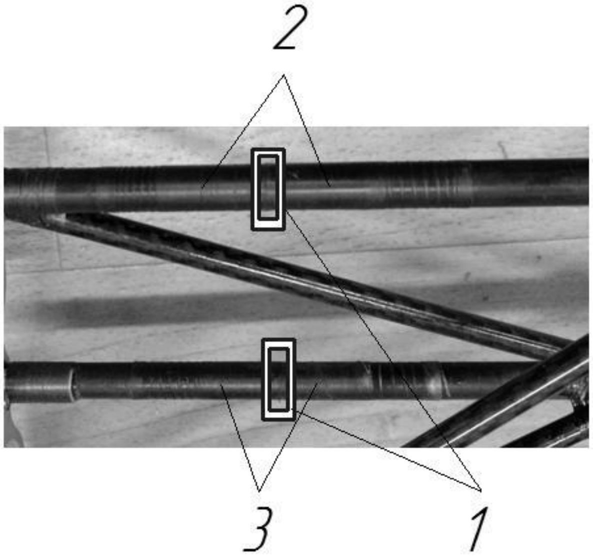

**Figure 8**. Use of coupling connection in the design of tail beam rods:

1 - location of the line connecting the sections (tubes) of the tail beam rods; 2, 3 - the surface of the winding of the edges of the sections with aramid thread, respectively, the side and middle rods.

***Manufacture of joints for tail beam rods and its bevels (application of the method of directional winding with aramid thread).***

The tail beam of the pseudo-satellite is a three-dimensional triangular structure, the basis of which consists of three longitudinal rods made of carbon tube with a cross section of 10 mm x 8 mm and transversal struts, which are made of carbon tube with a cross section of 7 mm x 6 mm (Figure 9).

**Figure 9**. Appearance of the main components of the tail beam of the pseudo-satellite

The fabrication of the tail boom was also associated with the selection of a suitable type of connection that would provide strength between the struts and the cross members. The main type was a"butt" joint with a shaped tilling "under the contour" of the end of the brace.

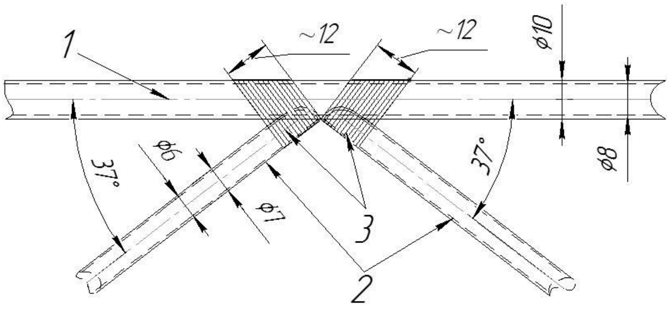

**Figure 10**. Diagram and dimensions of the connection of the rods and struts of the tail of the pseudo-satellite

This typical connection (Figure 10) consists of a rod 1, a carbon tube measuring 10 mm x 8 mm and struts 2, located at the junction with the rod at an angle of $37^0$. Braces - carbon tubes measuring 7 mm x 6 mm. To ensure the appropriate strength parameters, the rod and bevels are tightly "fastened" with aramid thread 3 (KEVLAR®29), which is then soaked with Sicomin SR1700 epoxy resin mixed with Sicomin SR7820 hardener [7, 8]. The scheme of forces acting on the tail beam is shown in figure 11; the case of loading of a tail beam by force $Y_{p.c.}$is consideredduring pitch control to change the horizontal flight to dive [9].

Aerodynamic force $Y_{p.c.}$ occurs when the angle of attack of the horizontal tail changes from zero to positive. At the same time, torque is generated on the $L_Y$ lever, which attempts to lift the tail boom and bend it. To emphasize its cantilever mounting (complete clamping in the attachment to the fuselage), the pseudo-satellite is conditionally stretched through point 0 (CG) by the suspensions OK and OM in which there are opposing and balanced forces (reactions of supports) $R_{s.\ CG}$ [10].

Under the action of the $Y_{p.c.}$force, the fuselage, together with the tail boom, tries to lower the nose, which is hindered by the Op.1 suspension. Therefore,the artificial "clamping" of the rear beam was obtainedfor the calculation.

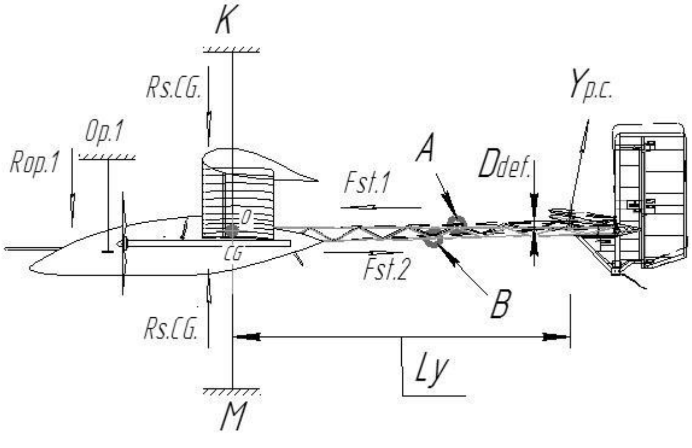

**Figure 11.** Diagram of the forces acting on the tail boom of the pseudosatellite (the case of changing the horizontal flight to a dive)

As stated above, the tail beam rises, but due to artificial "clamping" it undergoes elastic deformation and deformation at a distance $D_{def}$.

It is known that the rods will be compressed/stretched; under these conditions, the upper rod is compressed by the force Fst.1, and the lower is stretched by the force Fst.2 (Figure 11). The diagram shown in figure 12 allows us to consider in more detail the nature of loading at nodes A and B of this truss. The diagram shows the N-N1 neutral axis, which shows the bent beam configuration, but there are no loads along the axis. The N-N1 axis is at a distance of 1/2 L.

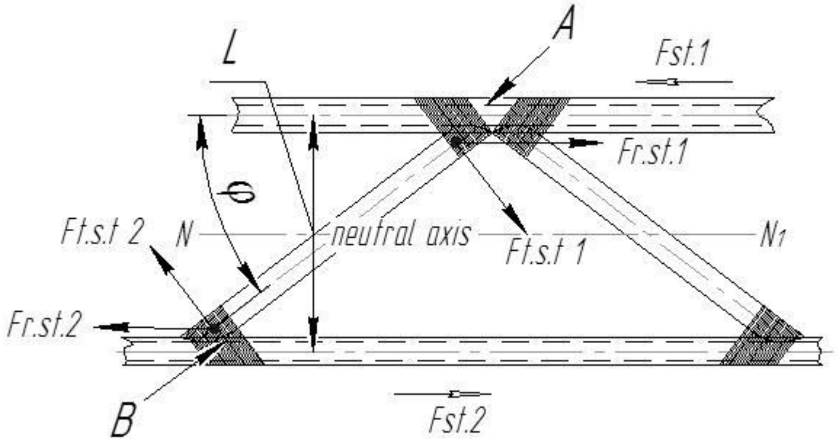

**Figure 12.** Scheme of formation of forces for breaking of aramid thread on connection of cores and braces of a tail beam

In nodes A and B develop counter-forces Fst.1 and Fst.2 corresponding reactions, designated as Fr.st.1 and Fr.st.2. Due to the fact that the connection is wedge-shaped, along with the named forces, there are forces that are aimed at stretching / breaking the threads of the connection, denoted as Ft.st.1 and Ft.st.2.

Numerically, the force Ft.st.1 (Ft.st. 2) can be found from the formula:

$$F_{t.st.1} = \mathrm{F}_{\mathrm{r.st.1}} \sin\varphi \tag{1}$$

The forces $F_{st.1}$ and $F_{st.2}$ (or their reactions) can be found from the formula (for the force $F_{st.2}$):

$$F_{st.2} = \frac{\mathrm{M}_{chp}}{{}^{1}/{}_{2}l} \tag{2}$$

In turn $M_{chp}$ (moment of control from horizontal plumage) represents the aerodynamic moment arising owing to action of force $Y_{p.s}$on the shoulder $L_y$ (Figure 11), which is calculated by the formula:

$$\mathrm{M}_{chp.} = Y_{p.s.} \times L_Y \tag{3}$$

The force $Y_{p.s.}$can be calculated using the known formula:

$$Y_{p.s.} = \left(\frac{\rho V^2}{2} \times C_y \times S_{h.p}\right) \tag{4}$$

where: $\frac{\rho V^2}{2}$ – dynamic air pressure;

$C_y$ – the coefficient of lifting force of the plumage at a given angle of attack;

$S_{h.p.}$ – area of horizontal plumage.

After substituting specific values of all quantities ($\rho$= 1,225 kg / $m^3$; $S_{h.p.}$ = 1,07 $m^2$; V = 6 m / s; $C_y$ = 0,34 (at $\alpha$ = 20)) in formula (4) we obtain:

$$Y_{p.s.} = \left(\frac{\rho V^2}{2} \times C_y \times S_{h.p}\right) = \text{ 8,02 kGf.}$$

To obtain the value of the bending moment from the action of the control force, the obtained value of the aerodynamic force from the horizontal plumage must be substituted into formula (3). According to the geometric data of the pseudo-satellite $\mathrm{M}_{chp.}$ numerically equal to: $\mathrm{M}_{chp.}$= 18.5 kgm.

This moment is applied to the neutral axis N-N$_1$. Since the rods of the tail beam are located at a certain distance from this axis, the force that stretches / compresses the rods will be equal to (for rod 1):

$$F_{st.1} = \frac{\mathrm{M}_{chp.}}{\frac{1}{2}L} = 184 \text{ к}Gf$$

Since the breaking force for the rod (Table 5) is 1698 kGf, respectively, the margin of safety (destructive overload) for the rod is:

$$n_{m.s.} = \frac{F_{d.st.1}}{F_{st.1}} = \frac{1698}{184} = 9{,}2$$

Based on the requirements for the strength of the pseudosatellite, according to which the destructive overload is $n_y = 7$, the ultimate strength of the rod under the action of the control force $Y_{p.s.}$ will be provided because $n_{m.s.}$is more than nominal by 31%.

In figure13 and figure14 examples of practical application of this type of connection for different components of the truss tail beam of the pseudo-satellite are given.

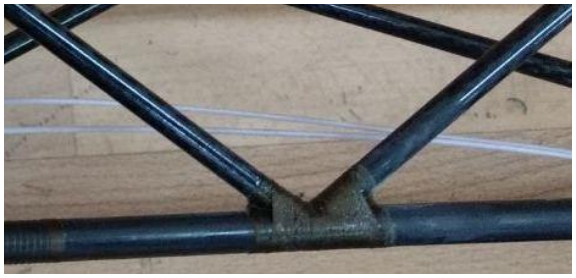

**Figure 13.** Aramid thread in the connection of the upper rods and the rods of the tail beam

**Figure 14.** Connection of upper and lower rods with braces and end frame of tail beam by means of aramid thread

## Conclusions

1. The rods and braces in the pseudosatellite design are a combination of products made of a carbon tube and duralumin tips glued into it. Due to the nature of the brace loads, the axial force is mainly initiated by tensile loads, therefore the critical cross-sections of a typical Rod (brace) are the carbon tube cross-section, tip cross-sections, and the bonding surface of the carbon tube and tip.

2. The rods of the tail boom of the pseudo-satellites are combined products made of a carbon tube and carbon inner couplings, joined by an adhesive composition of Sicomin SR7100 glue mixed with Sicomin SR7105 hardener. According to the calculated data obtained, the minimum breaking force of 1698 kgf (16640 kN) corresponds to the cross-section of the carbon pipe, of which the tail boom rod consists.

3. The connection of carbon tubes with aramid thread provides the minimum weight and maximum destructive force of 3588.6 kGs (35.168 kN), which is required for the destruction of the glued connection between the carbon tube of the rod, its winding and the rods.

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