Project 10- Fittings design.

1. Fiting design

The student should chosse the type of wing fitting coresponding to previous projecet. If Student designed wing and fuseladge conection as a monocoque/semi-momocoque than Student should assume wing structure with two spars and three lugs (Figure 3). In that cese the distance between spars should be equal to distance beetween WALL. The results of this part of project should be geometry of the fitings which can transferred all loads.

1.1. Loading transferred by the wing

This part of the project guide is focused on calculations of wing fitting. The presented analysis will be simplified. The Figure 1 presents loading transferred by the wing. Designations shown in Figure 1 are being used in this project guide.

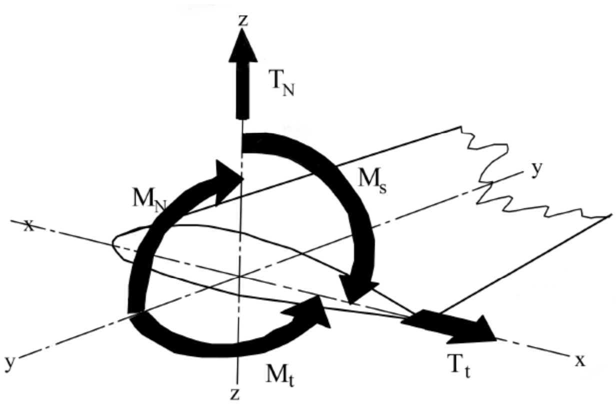


Figure 1 The loading transferred by the wing [2]

Where:

M_t- Tangential bending moment

M_N- Normal bending moment

M_S- Torsion moment

T_t- Tangential transverse force

T_N- Normal transverse force

1.2. Type of wings fittings

Fittings are being used for joining the wings together and with the fuselage. We differentiate two basic types of connections:

- Right and left wing joined together. A fuselage is mounted later to wings unit. The wing-fuselage fittings carry only torsion moment and transverse force. Bending occurs only in the wings structure. This is the most common type in gliders as it offers the most simple and lightest solution. But not always this type can be used due to limitations imposed by the proposed type of wing-fuselage joint.

- In the second type wings are connected with the center bridge of the fuselage which is involved in the transfer of bending forces from the wings, takes over transverse force and torsion moment. Compared to the first type it must be mentioned that the main (front) and back fittings used in the system are more complex.

Fittings' construction solutions can be very different, due to the fact that they need to be adapted to the specific structure of the wing, however, they still possess some common elements thus stress and strain calculations can be based on the same basic principles.

Typical solutions used for the first type of fittings are presented in Figure 2. In the A scheme the visible part of the wing spar is ended with a pin(1), which enters the bush(2) in the other wing and vice versa. The fuselage is suspended on pins entering front(3) and rear(4) bushes. In B type of fitting, U shaped part of wing spar is placed over a single blade of the other wing's spar. Both are joined together with two pins (1)&(2) in the horizontal axis, parallel to longitudinal axis of the fuselage. Mounting of the fuselage is identical to the A-type, using bushes (3)&(4).

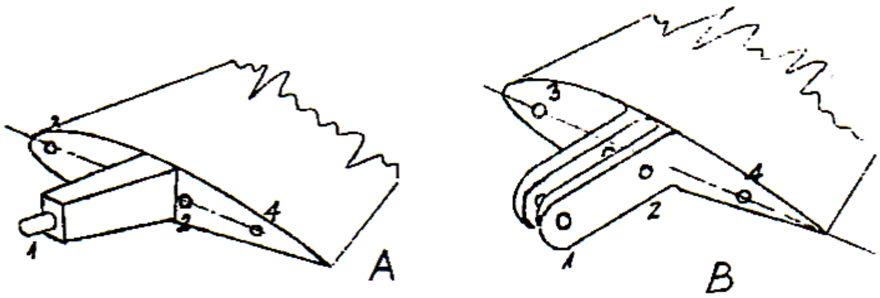


Figure 2 Wing-fuselage fittings of the first type [2]

The second mounting system is shown in Figure 3. All loads from the wings are taken over by the central bridge in the central part of the fuselage. Fittings in the form of lugs joined with top&bottom spar caps enter the pockets in the fuselage and are secured with a vertical pin. Rear fittings enter the U-shaped fuselage fitting and is joined with a horizontal pin parallel to the wing chord. Normal bending moment is transferred to the central part of the fuselage through the nodes (1) and (2), transverse force and torsion moment is transferred by nodes (1), (2) and (3).

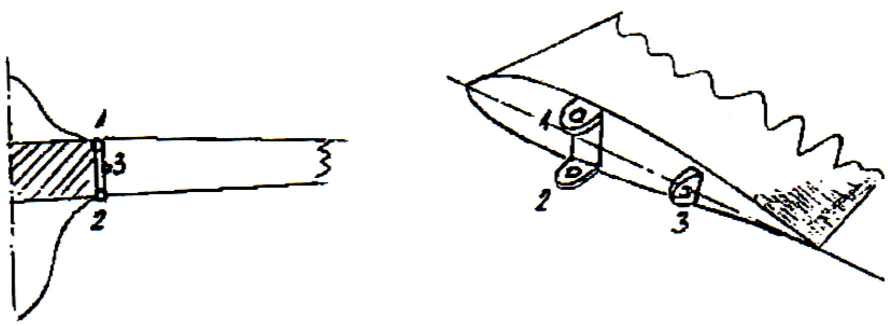
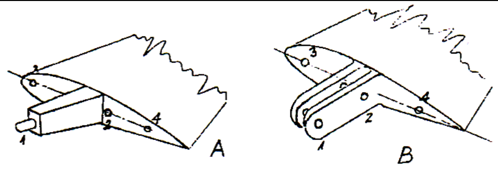
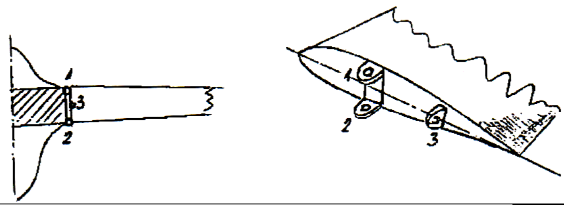
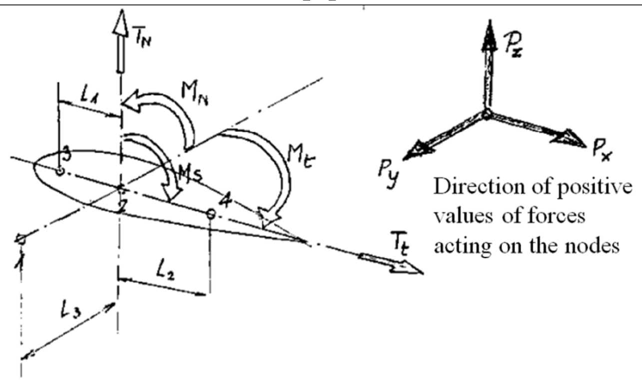
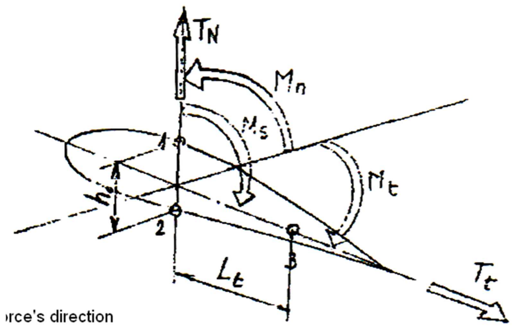


Figure 3 Wing-fuselage fittings with a central part of the fuselage bridge [2]

1.3. Loads on fittings

The following table includes formulas necessary to calculate forces loading fitting's nodes:

First type of mounting system (bayonet)	Second type of mounting system (centre bridge)
 [2]	
	
Forces in node 1: $P_{X_1} = 0$ $P_{Y_1} = 0$ $P_{Z_1} = -\frac{M_N}{L_3}$ Forces in node 2: $P_{X_2} = 0$ $P_{Y_2} = 0$ $P_{Z_2} = \frac{M_N}{L_3}$ Forces in node 3: $P_{X_3} = \frac{1}{2} T_t$ $P_{Y_3} = 0$ $P_{Z_3} = T_n \frac{L_2}{L_1 + L_2} + M_S \frac{1}{L_1 + L_2}$ Forces in node 4: $P_{X_4} = \frac{1}{2} T_t$ $P_{Y_4} = 0$ $P_{Z_4} = T_n \frac{L_1}{L_1 + L_2} - M_S \frac{1}{L_1 + L_2}$	Forces in node 1: $P_{X_1} = \frac{1}{4} T_t$ $P_{Y_1} = \frac{M_n}{h_0} - \frac{M_t}{2L_t}$ $P_{Z_1} = \frac{1}{2} T_n + \frac{1M_S}{2L_t}$ Forces in node 2: $P_{X_2} = \frac{1}{4} T_t$ $P_{Y_2} = -\frac{M_n}{h_0} - \frac{M_t}{2L_t}$ $P_{Z_2} = \frac{1}{2} T_n + \frac{1M_S}{2L_t}$ Forces in node 3: $P_{X_3} = \frac{1}{2} T_t$ $P_{Y_3} = \frac{M_t}{L_t}$ $P_{Z_3} = -\frac{1M_S}{2L_t}$

1.4 Stress in the bayonet

Using symbols from Figure 4, the stress in bayonet spar caps resulting from the tangential bending moment can be calculated as follows:

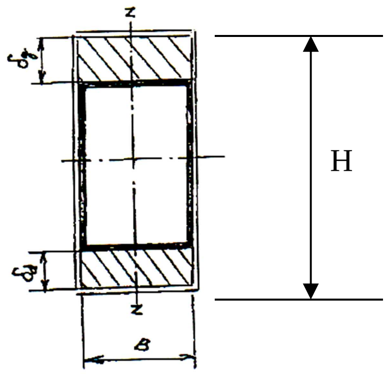


Figure 4 Bending by the tangential moment [2]

$$\sigma_{M_t} = \frac{6M_t}{B^2(\delta_g + \delta_d)} \qquad (1)$$

M_t- Tangential bending moment

σ_{Mt}- stress in spar caps

They should be added with stresses resulting from bending by normal moment calculated from equations:

$$h = H - \frac{\delta_g + \delta_d}{2} \qquad (2)$$

$$P = \frac{M_N}{h} \qquad (3)$$

$$F_d = B \cdot \delta_d, \qquad F_g = B \cdot \delta_g \qquad (4), (5)$$

$$\sigma_{Mng} = \frac{P}{F_g}, \qquad \sigma_{Mnd} = \frac{P}{F_d} \qquad (6), (7)$$

The way how forces are transferred in nodes depends on fitting's construction. The calculation method should be individual, but here a few general rules making fitting's designing easier are presented.

1.5. Strength of pin joint

Typical pin joint presents Figure 5

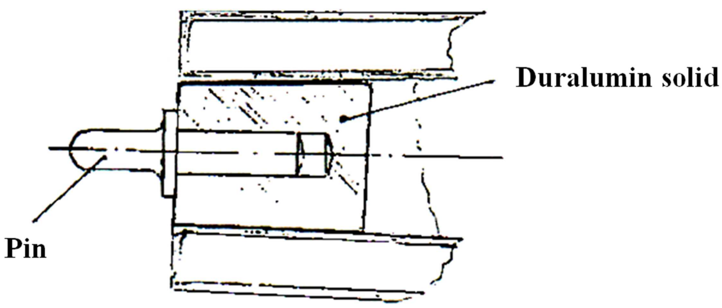


Figure 5 Pin joint [2]

The pin (Figure 5) extending out from the face of one spar comes into the bush in the rib of second half of the wing. The pin is embedded in duralumin solid which is bonded between two walls of the spar (Figure 5).

The force P_z causes bending and shear of the pin.

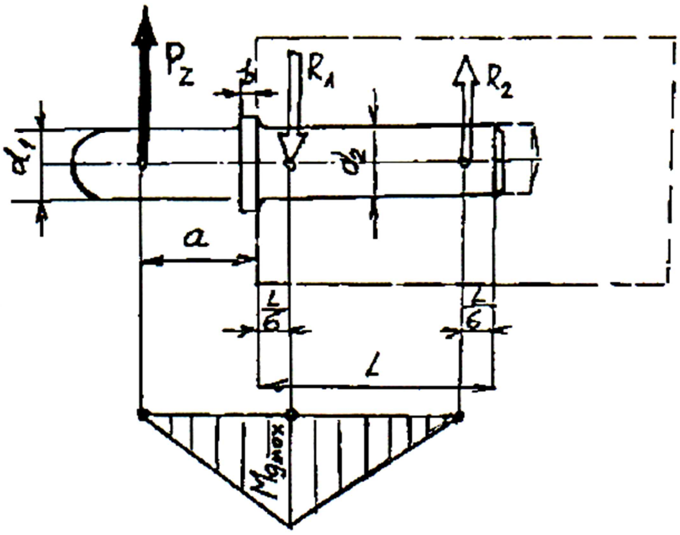


Figure 6 Load of the pin joint [2]

According to symbols in Figure 6 maximum bending moment of the outer part of the pin can be calculated from equation (8) .

$$M_{gmax}^{*} = P_z \cdot (a - b) \qquad (8)$$

The stress caused by the bending moment can be calculated from equation (9).

$$\sigma_1 = \frac{M_{gmax}^{*}}{\frac{\pi \cdot d_1^3}{32}} \qquad (9)$$

The stress caused by pin shearing can be calculated from equation (10).

$$\tau = \beta \cdot \frac{P_z}{\frac{\pi \cdot d_1^2}{4}} \qquad (10)$$

where β=1.33, is the shape factor for circle cross section.

The maximum bending moment in part of pin joint inside the solid (Figure 6) can be calculated from equation (11)

$$M_{gmax} = P_z \cdot \left(a + \frac{L}{6}\right) \qquad (11)$$

The stress caused by the bending can be calculated from equation (12).

$$\sigma_2 = \frac{M_{gmax}}{\frac{\pi \cdot d_2^3}{32}} \qquad (12)$$

The shearing caused by reaction R_2 can be calculated form equation (13).

$$\tau = \beta \cdot \frac{R_2}{\frac{\pi \cdot d_2^2}{4}} \qquad (13)$$

Where R_2 is force reaction.

$$R_2 = P_z \cdot \frac{a + \frac{L}{6}}{L - \frac{L}{6}} = P_z \cdot \frac{6a + L}{5L} \qquad (14)$$

Safety factor have to be assigned according to steel material of the pin.
According to Figure 7 pressure onto the duralumin solid is equal to:

$$p = p_1 + p_2 = P_z . \left(\frac{1}{L \cdot d_2} + \frac{6 \cdot c}{L^2 \cdot d_2} \right) \qquad (15)$$

Safety factor:

$$v = \frac{R_{cdur}}{p} \qquad (16)$$

where: R_{cdur} – is ultimate compressive strength of duralumin (solid material).

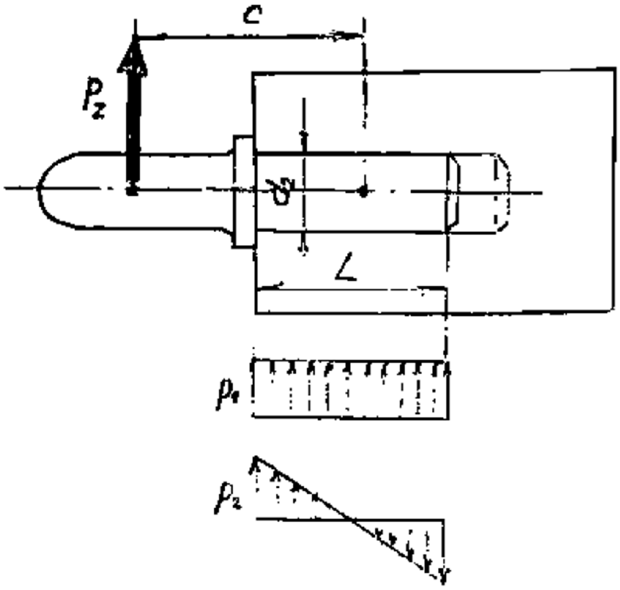


Figure 7 Forces acting on the pin joint [2]

The spar solid with pin is bonded into spar thru external surfaces of the solid (called F_s) on the both sides (Figure 8).

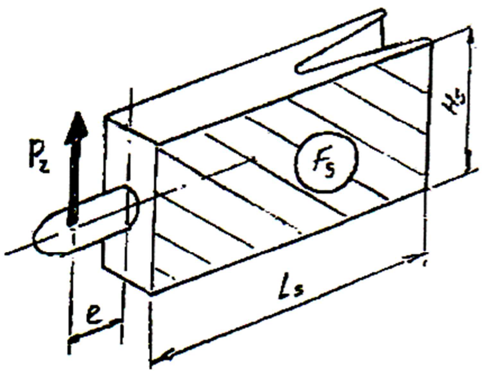


Figure 8 The spar solid with external surface Fs witch is bonded to the spar walls. [2]

According to Figure 9 the tangential stress on the external surfaces of the spar box is equal to:

$$\tau = \tau_1 + \tau_2 = P_z \cdot \left(\frac{1}{2 \cdot F_s} + 3 \cdot \frac{e + \frac{L}{2}}{F_s \cdot L} \right) \qquad (17)$$

The safety factor of bonding area can be calculated from equation (21)

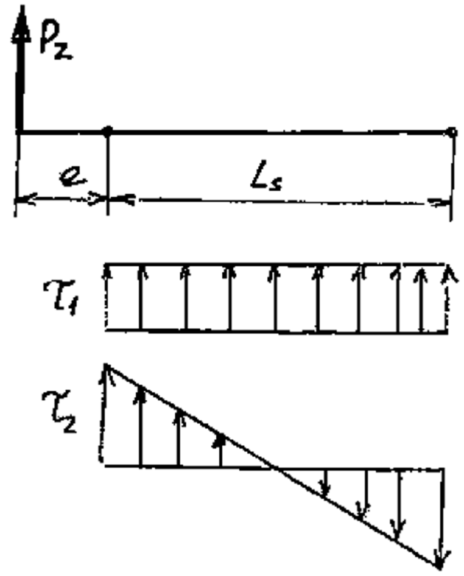


Figure 9 Tangential stress for bonding area [2]

1.6. Strength of lug.

The Figure 10 presents typical fitting of spar's cap which transferees load from spar's cap

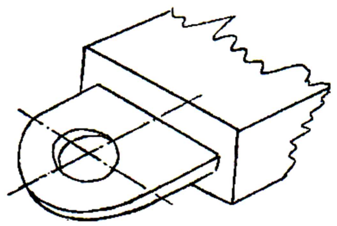


Figure 10 Cap's fitting [2]

The fitting can have different geometry: single lug (A) or double lug (B).

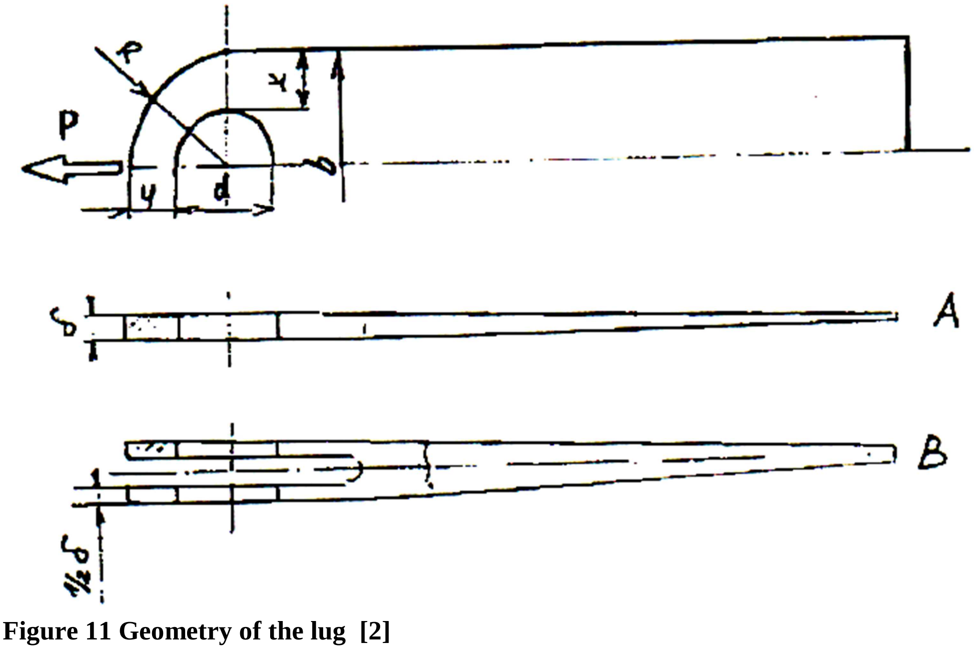


Figure 11 Geometry of the lug [2]

Stress in the lug related to cross section through the hole axis and perpendicular to the lug longitudinal axis:

$$\sigma = \frac{P}{K\delta(b-d)} \qquad (18)$$

where:
P – load,
K – stress concentration factor,
δ - lug thickness,
b – lug width in considered cross section,
d – hole diameter.
K factor is a function of hole position ($c = \frac{y}{x}$), lug width and hole diameter – K=f(c, b, d).
This can be found from the following diagrams (Figure 12 - Figure 14).

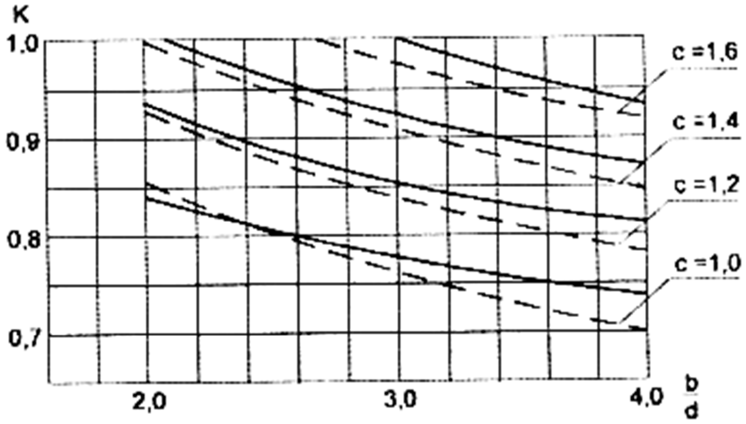


Figure 12 Diagram of stress concentration factor for normalized ordinary steel [2]

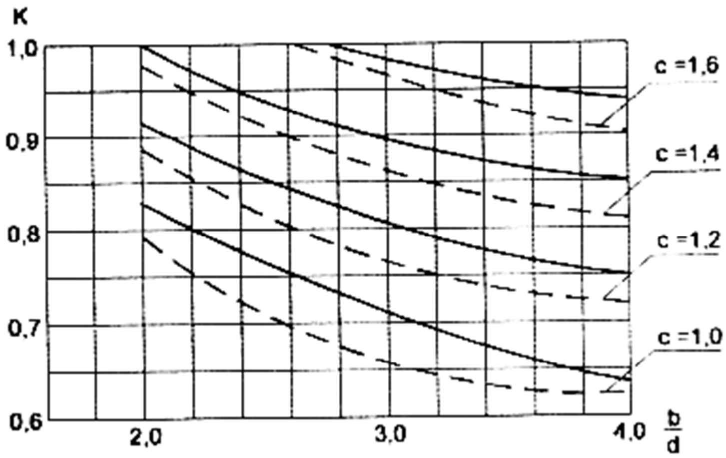


Figure 13 Diagram of stress concentration factor for alloy steel [2]

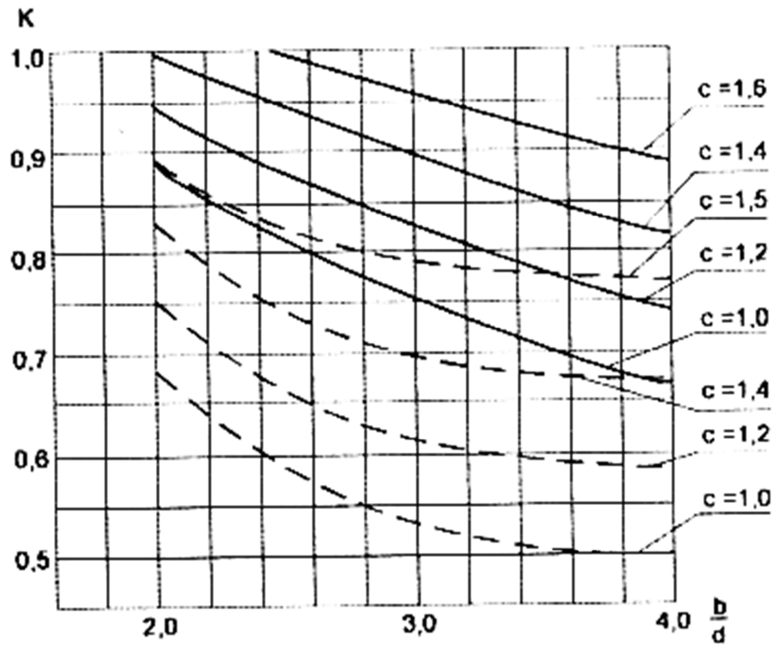


Figure 14 Diagram of stress concentration factor for aluminum alloys [2]

ATTENTION: In Figure 12-Figure 14 the continuous line is for single lug, dashed line is for multi lug.

Safety factor for lug:

$$\nu = \frac{R_{zm}}{\sigma} \qquad (19)$$

,where R_{zm} is fatigue strength of lug material.

It should be noted that thickness of fitting changes to make rigidity variation smoother.

If total thickness of both lugs (for U shape fitting) is not equal to the thickness of fuselage's lug (for single lug configuration) than this fact should be considered in equation (12).

To bond a metallic fitting to composite spar cap additional adhesive layer is used (e.g. BWF-21 for EPIDIAN resin). Only then adhesion is good enough to make connection durable enough.

Stress over bonding area:

$$\tau_{skl} = \frac{P}{2F_{skl}} \qquad (20)$$

,where F_{skl} is bonding area (one side)

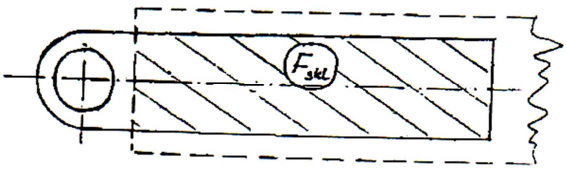


Figure 15 Fiting's bonding area [2]

Safety factor for bonding area:

$$\nu = \frac{R_{tkl}}{\tau_{skl}} \qquad (21)$$

,where $R_{tkl} = 700N/cm^2$ for EPIDIAN resin.

Equation above assumes constant distribution of stress over bond. That is applicable only for ultimate conditions. For limit loads there are stress concentrations on both ends of the bond.

One should take into consideration the fact that thickness of lug usually is not constant. The reason is to make smooth change of lug stiffness over spar connection area (ratio of fitting and composite spar stiffness). That ensures almost linear distribution of load over connection.

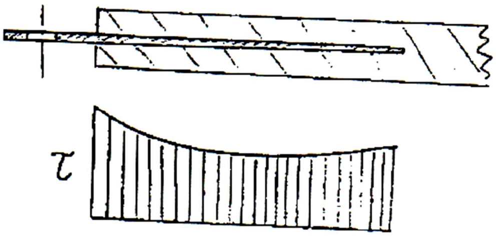


Figure 16 Shear stress distributions over bonding area [2]

1.7. Other types of fittings

Other types of fittings can be analysed according to chapter 7 in [4]

2. Project's requirements

Project's report should include:

- All project's assumptions
- Calculation of loads in each of fittings of selected type
- Calculation of stresses in each of fittings
- Sketch of all fittings geometry with dimensions
- Proposed materials for fittings
- Safety factors

References:

[1] M. Bijak-Żochowski, M. Detrich, T. Kacperski, J. Stupnicki, J. Szala, K. Szewczyk, J. Witkowski "Podstawy konstrukcji maszyn", tom 2, wydanie drugie

[2] W. Stafiej „Obliczenia stosowane przy projektowaniu szybowców"

[3] Michael C. Y Niu, "Airframe Stress Analysis and Sizing (3rd Edition)", 1997 AD Adaso/Adastra Engineering LLC

[4] Michael C. Y. Niu „Airframe Structural Design", Conmilit Press LTD, Hong Kong 1995