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STRENGTH CALCULATION OF UAV'S WING CONNECTOR TUBE

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Abstract: The use of unmanned vehicles - both civilian and military - is clearly a technological trend today. It is reasonable to assume that this trend will continue in the future. Especially in the military field, an unmanned vehicle can be considered a benefit, especially in applications where the use of "standard" equipment is difficult or impossible. This is especially true of Unmanned Aerial Vehicle (UAV). The flight itself represents a number of different types of stress affecting the design of the unmanned aircraft. Therefore, the design of such a device must be subjected in the first step to a computational strength analysis and subsequently to a real stress test. Our paper deals with the strength analysis of the most exposed structural element - the wing connector. Proper sizing of the wing connector is therefore crucial for the successful operation of the UAV.

Keywords: UAV; Wing connector; Normal bending stress; Strength calculation.

1 INTRODUCTION

The structural element that is subject to particularly high stresses (especially in bending) in the case of UAVs is the wing connector. This component connects both halves of the wing to each other and at the same time the wing with the fuselage. In our paper, the strength calculation of a bending of a wing connector is shown.

2 NORMAL BENDING STRESS OF A RIGID WING

We assume the existence of a connecting element of the tube type (Fig.1). The tube is stressed by the bending moment M_O.

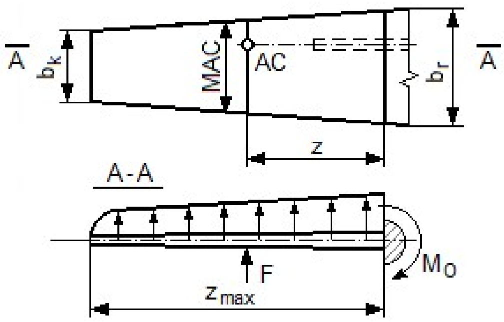


Fig. 1 Normal bending stress of the wing (AC – aerodynamic center, MAC – middle aerodynamic chord)
Source: authors.

The wing is stressed by a continuous load q, which is replaced by a tangential force F, which stress wing connector in bending. The bending moment induces a normal bending stress in cross section $\sigma = f(M_O(x))$ and a tangential force induces a shear stress: $\tau = f(T(x))$.

We calculate the normal bending stress according to:

$$\sigma = \frac{M_O}{W_O} = \frac{F.z}{W_O} \quad [MPa] \tag{1}$$

σ – normal tension
M_O – bending moment
F – tangential force
z – distance of the tangential force from the root of the wing
W_O – cross-sectional module

We determine the tangential force F from the following equation:

$$F = n_p . G . \frac{S_k}{S_c} \quad [N] \tag{2}$$

n_p – load factor
G – gravity of aircraft
S_c – total surface
S_k – wing surface

Load factor n_p we determine from the following equation:

$$n_p = \frac{F_p}{G} \ [-] \tag{3}$$

F_p – lift force
G – gravity of aircraft

Gravity of UAV is determined by relation:

$$G = m.g \ [N] \tag{4}$$

m – weight [kg]
g – gravity acceleration 9,81 [m/s^2]

Values of load factor for different types of UAVs are listed in Tab. 1.

Tab. 1 Numerical multiple of n_p for different types of UAVs

Type of UAV	n_p
Motorized aircraft	15
Glider	10

Source: authors.

Wing surface S_k we calculate according to the following relation

$$S_k = (b_r + b_k).\frac{z_{max}}{2} \ [mm^2] \quad (5)$$

b_r – wing root depth
b_k – depth of wingtip
z_{max} – wingspan

The distance of the tangential force from the wing root is determined from the following relation

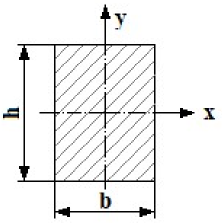
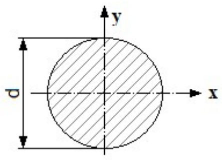
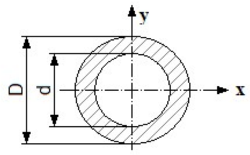
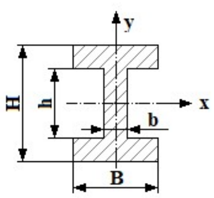
$$z = \frac{z_{max}}{3}.\left(1 + \frac{\eta}{\eta+1}\right) \ [mm] \quad (6)$$

η – ratio factor

$$\eta = \frac{b_k}{b_r} \ [-] \quad (7)$$

The cross-sectional module in the bend W_O depends on the cross-sectional area. The values of the cross-sectional module to the x-axis passing through the center of gravity for different cross-sections are given in Tab. 2.

Tab. 2 Section modulus W_O

Cross-section profile	W_O
	$W_O = \frac{b.h^2}{6}$
	$W_O = \frac{\pi.d^3}{32}$
	$W_O = \frac{\pi.(D^4 - d^4)}{32.D}$
	$W_O = \frac{(B.H^3 - b.h^3)}{6H}$

Source: authors.

The strength condition for pure bending is:

$$\sigma_{max} < \sigma_D \quad (8)$$

The course of the maximum normal stress for circular cross-sections is shown in Fig. 2. and rectangular cross-sections is shown in Fig. 3.

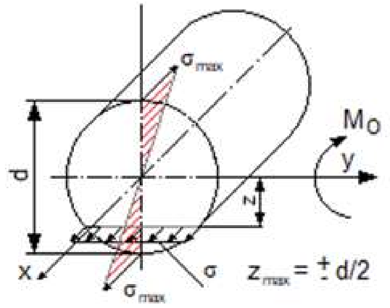


Fig. 2 Stress course in circular cross section
Source: authors.

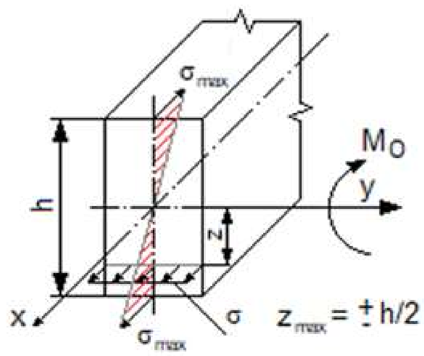


Fig. 3 Stress course in rectangular cross section
Source: authors.

For metallic (tough) materials, the normal tensile stress is the same as the normal compression stress. For wood and brittle materials, the normal tensile stress is not equal to the normal compression stress $\sigma_{maxt} < \sigma_{maxd}$.

Allowed normal tension σ_D we determine from strength limit R_m and safety factor k

$$\sigma_D = \frac{R_m}{k} \ [MPa] \quad (9)$$

σ_D – allowed normal tension
R_m – strength limit
k – safety factor $k = 1{,}2 \ \div 2{,}5$

Tab. 3 Strength limit R_m of some materials

Material	R_m	R_m **(after precipitation hardening)**	**Note**
	[MPa]	[MPa]	
Steel, class 11	400	-	ČSN 11 373
Steel L-ROL	550	1100	ČSN 14 331.7 (aircraft steel)
Duralumin	230	450	42 4203.6
European spruce	40	-	Along the threads
Pine	40	-	
European beech	45	-	
Soft balsa	5	-	0,15 kg/dm^3
Hard balsa	20	-	0,25 kg/dm^3

Source: authors.

3 STRENGTH CONTROL OF THE WING CONNECTING TUBE OF UAV – EXAMPLE

The basic dimensions of the wing are shown in Fig. 4. The weight of the aircraft is $m = 10\ kg$. The connecting pipe is made of duralumin with a diameter of 35 x 1.5 mm.

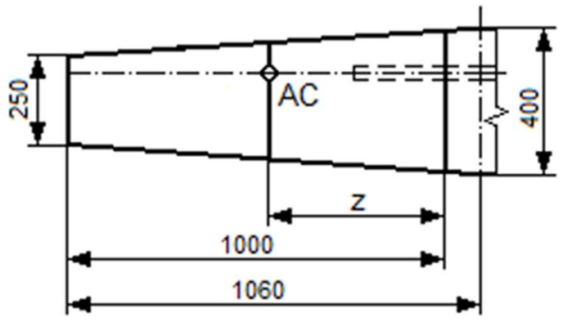


Fig. 4 Basic dimensions of the wing
AC – place of force F
Source: authors

Wing surface:

$$S_k = (b_r + b_k).\frac{z_{max}}{2}$$
$$S_k = (400 + 250).\frac{1\ 000}{2}$$
$$S_k = 325\ 000\ mm^2$$

Total surface:

$$S_c = 2(S_k + S_T)$$
$$S_c = 2\big(325\ 000 + (60\ .400)\big)$$
$$S_c = 698\ 000\ mm^2$$

S_T – the area of the fuselage between the wings

Ratio factor:

$$\eta = \frac{b_k}{b_r}$$

$$\eta = \frac{250}{400}$$

$$\eta = 0{,}625$$

The distance of the tangential force from the wing root:

$$z = \frac{z_{max}}{3}.\left(1 + \frac{\eta}{\eta+1}\right)$$

$$z = \frac{1\ 000}{3}.\left(1 + \frac{0{,}625}{0{,}625+1}\right)$$

$$z = 462\ mm$$

Tangential force:

$$F = n_p.G.\frac{S_K}{S_C}$$

$$F = 15.10.9{,}81.\frac{325\ 000}{698\ 000}$$

$$F = 685\ N$$

Cross-sectional module:

$$W_O = \frac{\pi.(D^4 - d^4)}{32.D}$$

$$W_O = \frac{\pi.(35^4 - 32^4)}{32.35}$$

$$W_O = 1\ 268\ mm^3$$

Normal tension

$$\sigma = \frac{M_O}{W_O} = \frac{F.z}{W_O}$$

$$\sigma = \frac{685\ .462}{1\ 268}$$

$$\sigma = 250\ MPa$$

Strength condition

Allowed tension:

$$\sigma_D = \frac{R_m}{k}$$

$$\sigma_D = \frac{450}{1{,}2}$$

$$\sigma_D = 375 \; [MPa]$$

$$\sigma = 250 \leq 375 = \sigma_D$$

Dural tube 35x1.5 mm meets the normal bending stress requirements.

4 CONCLUSION

The above calculation represents the basic strength control – only in bending. For a more comprehensive assessment of the strength of the wing connector, it would be necessary to supplement the shear control and then we should consider the combined stress (bending + shear).

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